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THE LEAD AND ZINC DEPOSITS OF THE BOU BEKER–TOUISSIT AREA, EASTERN FRENCH MOROCCO.[1]

JACQUES CLAVEAU, JEAN PAULHAC, AND JEAN PELLERIN.

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INTRODUCTION.

THE northwesternmost corner of Africa is crossed by an ENE metallogenic belt that in Morocco coincides with the mountain ranges of the Atlas orogenic system. Though the belt is noted, especially in southwestern Morocco, for occurrences of molybdenum and cobalt, and for appreciable manganese, it is primarily along its whole length a lead-zinc-copper belt.

The occurrences of those three metals are extremely common throughout the three atlasic ranges of French Morocco, namely, the Anti, High, and Middle Atlas, but few of them, however, have turned out to be of sufficient importance to form sizable mines.

The only large deposits known at the present time consist of lead and zinc only and have been developed in the course of the past five years in the hills of the Middle Atlas of Eastern Morroco. The occurrences are strung along an eastnortheasterly axis, some 10 to 15 km in length, running through the mining agglomerations of Touissit and Bou Beker in Morocco, and extending for some distance in Algeria.

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GEOLOGY.

The Bou Beker-Touissit area is located in the Tlemcen mountains of the Middle Atlas range. It lies at the eastnortheasterly end of a broad shallow depression known as the plain of Missouine and at the foot a long northwest scarp—the Rass Asfour scarp—that forms the southern edge of an elevated area termed, locally, the Rass Asfour Plateaux.

The rocks of the area are essentially sedimentary and belong almost exclusively to the Jurassic that forms a series of more than 1,500 m of calcareous shales, sandstones, limestones, and dolomites. The base of the Jurassic is separated from the old metamorphosed and peneplaned Paleozoic surface by a thin formation of reddish conglomerate and red clays of unsettled age, and that could be assigned to the Permo-Triassic, Triassic, or to the base of the Jurassic itself.

The Paleozoic basement consists of highly folded red schists and gneisses with associated acidic (granitic and rhyolitic) to intermediate (dioritic and andesitic) igneous rocks.

Leaving aside the red formations of possible Triassic age, the Jurassic may, for the present purpose, be divided as follows:

Upper Jurassic	Portlandian Kimeridgian	Limestones and dolomites	600 m.
	Upper Lusitanian	Thick sandstones with subordinate calcareous shales	450 m.
	Lower Lusitanian	Mostly calcareous shales (marls)	5–130 m.
	Oxfordian Callovian	Mostly marls topped by a thick sandstone horizon	200–250 m.
Middle Jurassic	Dogger	Limestones	0–4 m.
Lower Jurassic	Lias	Dolomites	From 0 to 150 m. or more

The Jurassic as a whole is practically unfolded, but it is broken into large structural blocks of the horst and graben type by a series of regional east-northeasterly faults that have their roots in the Paleozoic basement. It has generally been believed that the horsts represent more resistant units of Paleozoic rocks, that is, units of igneous rocks or metamorphic gneisses, whereas the graben areas consist mostly of weak units of Paleozoic schists. As far as it has been possible to ascertain thus far, it would seem that this belief is justified.

The structural blocks of direct concern include a major horst following the Bou Beker-Touissit axis and known as the *Bou Beker horst,* and its two counterpart depressed areas, namely, the *Missouine graben* on its southeast side, and the stratigraphically *depressed area of the Rass Asfour Plateaux* on its northwest side.

The Bou Beker horst is expressed topographically by a long and low

ridge sloping gently eastward and ending in a sharp brow at its west end. The latter, marked by a cliff of hard Lias dolomites and underlying Paleozoic rocks, coincides with the termination of the horst structure that is interrupted here by the convergence of its north border fault upon its south border fault (Fig. 1). The gentle eastward slope of the ridge reflects a plunging attitude of the horst that causes the Lias dolomites, exposed at the west end, to disappear rapidly eastward under an increasingly thicker Jurassic cover.

The Rass Asfour Plateaux that stand topographically well above the Bou Beker ridge constitute, nevertheless, a stratigraphically depressed area and thus illustrate a case of inverted relief, that is, of a structurally downfaulted area now lying topographically higher than the upfaulted zones.

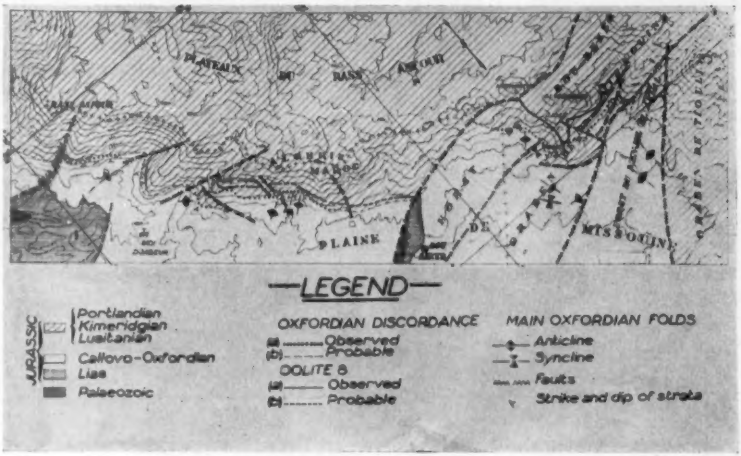

FIG. 1.

The Bou Beker horst is bounded on the north by a sharp fault with a throw of 200 to 300 m. Though it plunges east, it is also tilted toward the southeast, and thus falls progressively toward the graben of Missouine to which it finally passes by a series of small discontinuous step faults, one of which is more continuous and important than the others and is called the south border fault of the horst.

The graben of Missouine is succeeded on the southeast by other major structural blocks (Fig. 1) including first the horst of Menjel el Akhal, that is raised stratigraphically 100 m above the graben of Missouine, and, second, the graben of Tiouli, another powerful structural unit that, like the Rass Asfour unit, exhibits the phenomenon of inverted relief.

It is clear that the major faults of the area were in existence in the Paleozoic basement at the beginning of the Jurassic and that, during the interval between the end of the Paleozoic peneplanation and the deposition of

the lower Jurassic, the various structural Paleozoic units were affected by differential movements that led to uneven deposition of the Lias dolomites. If it is assumed that the thickness of the Lias reflects the Paleozoic relief at the beginning of the Jurassic it can be surmised, on the whole, that at that time the Rass Asfour graben and Tiouli graben, in which the Lias is very thick, were greatly depressed with respect to the three central units, namely, the horsts of

MESOZOIC	UPPER JURASSIC	PORTLANDIAN-KIMERIDGIAN		600	Limestones and dolomites	600m
		LUSITANIAN	UPPER LUSITANIAN	400-450	Transitional zone to Ls and dol.	10-20
					Thick sandstones units	60
					Soft greenish limestones	45-50
					Thick sandstones	75
					Marls+ss	135
					Thick sandstones/ferruginous in part	165,170
					Marls	20
					Marls and sandstones	60
					Oolite 8 (red)	15cm
			LOWER LUSITANIAN (Part. missing in Rass Asfour)	130	Marls+ss	50
					Oolite 7	40cm
					Marls+ss	35-40
					Oolite 6	6cm
					Marls+ss	35-40
					Oolite 5 (discordant)	4-25cm
		DISCORDANCE				
		CALLOVO-OXFORDIAN	OXFORDIAN	250	Ss+marls (Oxfordian ss)	50-60
					Oolite 4 (Calcareous)	5-50cm
					Marls+ss	90-120
			CALLOVIAN		Oolite 3	30-50cm
					Marls+ss	40-65
					Oolite 2 (Callovian)	30cm
					Marls ss (Bou BeKer ss locally)	30-40
	MIDDLE JURASSIC	DOGGER	BATHONIAN (BAJOCIAN) (AALENIAN)	4 0	Oolite 1 (Bathonian)	85cm
					Limestone marls, ss	1-3
	LOWER JURASSIC	LIAS	(TOARCIAN) (DOMERIAN)	0-150	Marly dolomite	0-2
					Motley dolomite	
					Sublithognaphic Ls	0-4
	Possibly TRIASSIC (?)			0-6	Red clays and conglomerate	0-6
		GREAT UNCONFORMITY				
PALAEOZOIC					Schists metamorphic gneiss igneous rocks	

FIG. 2. Table of formations.

Bou Beker and Menjel el Akhal and intervening Missouine graben, in all of which the Lias is relatively thin.

Looking further into those three central units, it is found that the eastern part at least, of the graben of Missouine, was elevated with respect to the bordering "horsts," with the horst of Menjel el Akhal being probably more depressed than that of Bou Beker. The thickness of the Lias in the Bou Beker horst stays around 30 m whereas in the Menjel el Akhal horst it is around 60 m. The Lias of the graben of Missouine is thin (1–2 m), or even totally lacking, east of the Gabet el Abed and becomes progressively thicker southwestward.

The structural blocks appear to have remained quiet until the end of the Oxfordian. The Jurassic sediments, resting then on the Paleozoic basement, included the dolomitic Lias at the base, followed upward by the thin Dogger limestones and 200 m of calcareous shales or marls topped by 50–100 m of thick sandstone units.

It seems that at the end of the Oxfordian extremely violent movements occurred in the Paleozoic basement which, transmitted as powerful shock waves through the plastic marls, caused the overlying sandstones to become erratically folded and disrupted. Using a perhaps not fully adequate but realistic comparison, one may picture the great plastic mass of marls as shaken by great waves and associated ripples, and the semi-rigid overlying sandstones accommodating themselves in various ways to this sudden instability. The resulting picture is one of a few fairly harmonious folds, but more commonly of disorderly folding, wrinkling, and fracturing.

This disturbance can be termed the "Oxfordian folding," a term that may be exaggerated at the scale of true orogenic folding, but that is adequate to describe this highly disturbed horizon among the otherwise little disturbed Jurassic series. The areal extent of the Oxfordian folding has not yet been determined. It is known at present to be over more than 50 square kilometers and it is obviously much more extensive. The folded sandstone horizon was then submitted to rapid erosion, very likely of submarine nature, and the Oxfordian leveled off into a great submarine terrace. It is on this eroded surface that the lower Lusitanian was deposited in great angular discordance with the Oxfordian sandstones. However, the deposition of the Lusitanian was preceded by new adjustments of the structural units, and the three units—Bou Beker horst, Missouine graben, and Menjel el Akhal horst—were depressed with respect to the Rass Asfour structural unit, a condition that was thus the reverse of the actual condition, and which could be referred to as "inverted tectonics." Lower Lusitanian sediments thus began to accumulate on the depressed segments of the Oxfordian terrace, south of the northern fault of the Bou Beker horst, long before being laid down on the raised segment of the Oxfordian terrace of the Rass Asfour structural unit. Accordingly, whereas the lower Lusitanian throughout the Bou Beker horst, Missouine graben, and Menjel el Akhal horst is about 130 m thick, it is never more than 50 m, and generally much thinner, throughout the Rass Asfour area.

The Oxfordian disturbance was obviously not the last movement to affect the major faults of the area, for most of the faults are now found to extend upward through all the post-Oxfordian series. There is one notable exception, however, of a major horst-graben fault that has not moved since the Oxfordian folding, namely, the south border fault of the Bou Beker horst.

It will be recalled that just before the Lias deposition, the "graben" of Missouine was raised with respect to the "horst" of Bou Beker, thus causing a complete to partial gap of Lias in the graben. During the Oxfordian folding, the graben was dropped some 20–25 m with respect to the horst, following which, erosion leveled off the horst-graben area, thus removing 20–25 m more of upper Oxfordian on the horst than on the graben. The fact that the lower Lusitanian is now found resting upon the leveled off Oxfordian erosion surface,

without any break where it overlies the horst-graben fault, shows that no movement has occurred along the south border fault of the Bou Beker horst since the Oxfordian folding.

The unusual absence of post-Oxfordian movement along this important fault, although puzzling in itself, is all the more so considering that the mineral deposits of the area are distributed along this fault. The question is raised: what relation can there be, if any, between the localization of the ore deposits and the absence of post-Oxfordian movements along the south border fault of the Bou Beker horst?

THE ORE DEPOSITS.

Structural Controls.—The deposits form stratiform, discontinuous bodies in the Lias dolomites at the base of the Jurassic, and are distributed on either side of an eastnortheasterly axis coinciding with the south border fault of the Bou Beker horst. This fault-axis, however, constitutes the regional or large-scale structural control, and the various ore bodies, though strung out along this major structure, are more directly controlled by minor fractures, fracture zones, or faults related to the fault-axis.

In the Bou Beker sector, the important occurrences of ore are either along the fault-axis or, more commonly, along a group of faults oriented between northeast and northwest, and branching out from the fault-axis. Some of these transverse fractures extend completely through the horst of Bou Beker to end up against its north border fault. The ore bodies are thus mostly within the horst structure with, nevertheless, some important, though low-grade, ore located within the graben area.

East of Bou Beker, there is a tendency thus far for the rich ore to occur in the graben along eastsoutheasterly fractures diverging from the south side of the fault-axis, whereas west of Bou Beker in the Touissit sector, the tendency is for the ore to form many small bodies lining up along northeast to east-northeast faults, with, however, one major elongated deposit occurring along a major eastsoutheast fault.

In practically all cases, the secondary structures with which the ore is associated are small structural features, such as faults with small throw or series of parallel fractures of the nature of shear zones, or perhaps weak flexures, all of which are fairly commonplace throughout the Lias in general. These features appear quite clearly to have been in existence before the ore deposition, and to have been the site of renewed movement afterwards.

The question as to why, of so many apparently similar small structural features that were all potentially favorable loci of deposition, only a few were actually mineralized, is most difficult to answer. To say that those features that were most directly connected with the "avenues of access" were those most heavily mineralized is obviously a very logical answer, but it seems altogether too simple and does not explain everything. On the other hand, it is possible that the small features that are now visible had little to do with the localization of the ore, and that the solutions were guided by more important

structures that have now disappeared, or that the geologist has not yet learned to identify.

Host Rock.—In the Bou Beker-Touissit area, the mineralization is strictly confined to the dolomitic Lias at the base of the Jurassic. The thickness of the Lias may exceed 100 m in some nearby graben areas, but it is less throughout the mineralized belt. It varies from 60 m in the Touissit sector to 20 m or less in the Algerian sector, the average for the Bou Beker central sector itself being of the order of 30 m. The Lias is separated from the Paleozoic metamorphic basement by a thin series of red sediments which, as discussed earlier, may be assigned to the early Lias. The red sediments pass upward without apparent break to sublithographic limestone of lenticular habit, and then into the dolomitic series that forms the bulk of the Lias.

The exact upper limit of the Lias is ill-defined, the dolomitic series passing gradually to black marly dolomite that passes in turn to the Dogger dolomitic and argillaceous limestones. In the eastern part of the area, the Dogger is commonly lacking, and the black marly dolomite is overlain directly by the thick series of Callovian marls.

The dolomitic Lias forms an assemblage of massive beds of coarsely crystalline dolomite, alternating with subordinate beds of finely crystalline brownish dolomite. The coarse dolomite consists of a typically grayish assemblage of dolomite crystals, whereas the brownish dolomite appears to be of an argillaceous or siliceous type. In localities of the eastern sector, this brownish dolomite is generally a fine aggregate of quartz and dolomite grains that probably represent the recrystallization of an originally siliceous dolomite, rather than a dolomite penetrated by hydrothermal quartz. A particularly characteristic feature of the dolomitic assemblage is the almost regular intercalation of thin beds of extremely fine textured whitish to beige dolomite, and of grayish or dark clay among the gray or brownish massive dolomites. The narrow clay horizons, or partings, are generally associated with the thin whitish beds, and both may be taken as marking a recurrent condition during which sedimentation was different from the normal dolomitic deposition. The clay beds, which carry thin coal lenses, indicate short periods during which clastic material, accompanied by plant debris, was being washed into the sea. The thin beds of beige dolomite, on the other hand, are commonly thought to represent dolomitized limestone beds.

The Lias has undergone a special phenomenon of recrystallization whose capricious and erratic results are not yet fully understood. This has yielded very complex bands in which the gray dolomite is invaded by white dolomite, forming a combination termed ***mottled dolomite.***

The bands of mottled dolomite alternate with bands of non-mottled dolomite, the latter being most commonly of the brownish rather than of the grayish type, which suggests that the mottled dolomite was formed in bands of particular chemical composition, presumably in those approaching the greatest dolomitic purity. It is probable that the white dolomite of a given band of mottled dolomite comes almost entirely from the solution and re-precipitation (accompanied by removal of the impurities) of part of the dolomite of that band. The process of purification is often strikingly demonstrated by the

presence of paper-thin linings of black muds at the contact of the white and gray dolomite. The aspects of the mottled dolomite are extremely varied but they may be regarded as falling into two types: *one* in which the white dolomite replaces the gray dolomite along certain original sedimentary features, including mostly sub-bedding planes, and *the other* in which the white dolomite replaces the gray dolomite along fractures.

The first type yields a typically banded assemblage of alternating white and gray dolomite, whereas the second type produces an assemblage resembling a breccia in which fragments of gray dolomite are recemented by the white dolomite. It is a particular breccia structure, however, in that the replacement has begun along a system of small irregular fractures and has proceeded gradually inward into the gray dolomite. Though it has not been possible to make an exhaustive study of the phenomenon, it appears in most cases observed that the fragments of gray dolomite have not moved; they, therefore, all maintain a common orientation.

It is unavoidable that the extensive intimate process of solution of the gray dolomite, and of its re-precipitation as white dolomite, has not always been confined to one given horizon and that liberated dolomite, recrystallizing as the white type, has migrated along fractures and effected some replacement of the ordinarily refractory, more impure, brownish dolomite. This liberation and migration explains the embayments of mottled dolomite into the brown dolomite, and the presence of innumerable veinlets and stringers of white dolomite throughout the whole Lias assemblage, and even far up into the overlying Dogger and Callovian marls. It also explains the drusy recrystallization of the white dolomite in some mottled bands, the areas where the greatest amount of geodes occurs representing those from which the greatest quantities of dolomite have migrated into neighboring horizons.

Localization of the Ore in the Host Rock.—The lead and zinc are generally associated with the horizons of mottled dolomite in which they replace first, the remaining gray dolomite element, and eventually the white dolomite element, the latter disappearing progressively as the ore gets richer. The horizons of non-mottled dolomite, and the thin recurrent zones of clastic sediments and dolomitized "limestones," remain highly refractory to replacement by lead and zinc, though some examples of their partial or total replacement have been noted in some unusually rich ore bodies.

As a general rule, the mineralization remains localized in the upper part of the Lias. Thus, where the Lias is 25 to 30 m thick, the lead and zinc occur within the first 15 to 17 m from the top. Its upper limit is the roof of marly dolomite, which is generally intensely pyritized but never mineralized in lead or zinc. Its lower limit varies, as a rule, according to the intensity of the mineralization. In other words, the mineralization decreases vertically upward before decreasing laterally. Rich "runs" may reach 11 to 12 m in thickness in their central part. This thickness may be constant for some width away from the longitudinal axis. Then, the ore disappears gradually at the lower levels and the last ore of the border of the band is found at the uppermost dolomitic levels.

In some localities of the Bou Beker sector, there occur twin concentrations of ore separated by a wide unmineralized vertical gap. Here, one of the tabular bodies occurs near the roof of the Lias and the other near the middle. This is a special case, however, of two phases of mineralization, as will be discussed below.

The Ore Bodies.—The ore occurs essentially as stratiform replacement bodies. These are commonly elongated with their long axis parallel to their respective controlling fractures or faults, but they may be of various shape and grade, from long and narrow, regular "runs" to broad, cloudlike, deeply embayed bodies with highly irregular boundaries; from bodies of rich massive sulphide to masses of low-grade, diffuse, mineralization.

There are two main types of ore, *one* consisting predominantly of sphalerite with subordinate to practically negligible galena, *the other* of galena alone. The ore of the first type may be a fine- to medium-grained crystalline aggregate of metallic, sub-metallic, or resinous sphalerite according to the various ore bodies. It tends to occur in closer relation to the eastnortheasterly fault-axis than the ore of the second type, though one instance is known of a fairly large body not very far south of the north border fault of the horst. The ore of the second type (galena alone) forms a coarse crystalline aggregate and has some peculiar characteristics of distribution. It occurs always in the uppermost dolomitic levels of the Lias and along transverse faults located in the highest parts of the horst of Bou Beker, that is, in the northwest sector of the horst, since the Lias dips to the southeast. Although the ore of the first type is known to have a broad vertical range from the top to below the middle of the Lias, its upper limit is drastically reduced in the known cases where it occurs with the ore of the second type, the latter occupying then the upper dolomitic levels and the ore of the first type being located near the middle of the Lias.

It is believed that the coarse galena of the upper levels represents a somewhat later stage of mineralization than the aggregate sphalerite-galena. That galena alone was deposited in the end phase of the mineralization is strikingly demonstrated in some of the rich zinc ore bodies of the eastern sector by the presence of vertical veinlets of galena cutting the massive sphalerite. There remains, however, to be explained why, in the sectors where both the first and second types of ore occur together, one below the other, the sphalerite ore, while being deposited in the middle part of the Lias, did not invade the upper Lias as well, since it was deposited first.

The two types of ore just described are essentially of the replacement type. A third type of ore, representing filling of cavities, may be mentioned. It is of rather restricted occurrence and is found in localities of the Bou Beker sector marked by a considerable development of drusy white dolomite. The sphalerite and galena fill the cavities and form beautiful encrustings with perfectly developed crystals, as well as botryoidal aggregates and various other structures characteristic of the deposition of minerals in voids or open fractures.

Apart from the two main sulphides of lead and zinc, notable quantities of pyrite, and locally of chalcopyrite, are found throughout the deposits. Small

quantities of quartz have been observed in the rich zinc ore bodies, but otherwise no gangue minerals have been introduced with the lead and zinc.

Oxidation of the Ore.—The oxidation of the ore constitutes a study in itself and it can be only briefly commented upon here.

The ore lying below the present hydrostatic level is unoxidized, which indicates that the underground water was never, at any time since the ore formation, at a lower level than at present. The ore lying above the present level is not uniformly oxidized, the irregularities corresponding to peculiarities of the underground drainage system. Some of the faults have a damming effect on the present underground flow, and cause the water to be retained in some structural blocks at a level above the average regional hydrostatic level. Through those beneficial irregularities of the drainage, large important portions of rich ore bodies have thus escaped deteriorating oxidation.

The common minerals of the oxidized zones include cerussite, anglesite, smithsonite, calamine, gypsum, native sulfur, and others. Wulfenite and vanadinite have been observed in rare instances.

Problems of Origin and Localization of the Ore.—The Bou Beker-Touissit lead-zinc occurences range among the great deposits of the world and compare favorably with those of southeastern Missouri and the Tri-State District. But if they have great geologic analogies with the American deposits, they also raise and leave largely unanswered, the same fundamental questions for the geologist, namely, where did the ore solutions come from; what were their avenues of access; why did the deposition occur strictly not only in the Lias but along certain preferred horizons of the dolomitic assemblage? The question of the source of the solutions must remain unanswered save for the patent fact that they originated somewhere deep in the Paleozoic basement.

The solutions ascended along fractures that went deep enough to tap them, such as those that limit the major structural blocks of the area. The actual distribution of the ore bodies suggests that the south border fault of the horst of Bou Beker was the most favorable channelway. It is not excluded, however, that possibly another structure such as the north border fault of the horst, which, at first glance, appears to be a more important structural feature than the south border fault, was the true tapping conduit at depth and that it is only farther up that the solutions were canalized into the south border fault. Only one major ore body is found in *direct* connection with the south border fault, all the others being localized along subsidiary fractures or faults of this main structure. The localization of ore along minor fractures, rather than along the major feeding structure of a mineralized area, is not an uncommon phenomenon and has been observed in many mining districts of the world, although it has never been explained satisfactorily.

The Paleozoic basement has not yet been studied in very great detail, but there is some indication that the south border fault of the horst of Bou Beker marks the contact between a predominantly eruptive nucleus to the north and a schist area to the south. This indication has already been indicated in the discussion of the geology of the area, when it was stated that probably the horst structures represented cores of igneous rocks.

The igneous rocks, however, are all pre-Jurassic in age and can have no

genetic relationship to the ore. They are of interest only in that they constitute rigid units capable of developing deep fractures that in combination with the damming effects of the bordering units of soft, plastic, impervious schists, could have made ideal channels of ascent for solutions originating from some deeply-buried intrusive mass. At this point, the question of "roots" of the deposits is naturally raised. Should it not be possible to find traces of the passage of the solutions through the Paleozoic basement? It seems that some traces should have been left but they are few and inconspicuous, and it will take considerable time and effort to disclose them. The discoveries made thus far in this direction amount only to the disclosure of one or two cases of small lead or zinc stringers, and of quartz-barite veins in the Paleozoic rocks.

It may be that in time some strategic area will be uncovered that will show lead-bearing quartz veins cutting the basement under some of the ore bodies, for we know that such occurrences exist elsewhere in the neighboring areas, such as in the Ghar Rouban horst, 15 km north of Bou Beker.

The localization of the deposits in the Lias dolomites can be explained *first* by the natural affinity of lead and zinc for dolomites and limestones, and *second* by the fact that the Lias is overlain by a thick series of marls that were impervious to the ore solutions.

The occurrence of ore along certain preferred horizons of the Lias is explained by the chemically favorable character of certain dolomitic bands, the bands that were mineralized being those that were most readily dolomitized, and thus made receptive to the ore solutions. In some instances, the impervious clay beds or partings occurring throughout the dolomitic series have played a part in controlling the ore deposition within a certain vertical range in the dolomites. The effect of those beds on the deposition is erratic, however, and of little importance on the whole. It has been suggested that the thickness of the Lias was an important factor in the ore deposition, the belief being that the rich ore occurs in the relatively thin Lias only. It is true that in the Bou Beker area the deposits occur exclusively in Lias that do not exceed 30 m, but it may be coincidental and due to the fact that the favorable structural controls happen to cross an area where the Lias is thin. In the Touissit sector, the deposits are in thicker Lias (up to 60 m).

A thin Lias may obviously avoid too great a dissipation of the solutions and thus favor greater concentration. But it seems that the amount of solutions that entered the Lias dolomites of Bou Beker was so great that it would still have produced great ore bodies even in a much thicker dolomitic series.

It thus appears more likely that the localization of the ore is a question of the right "feeder" fractures rather than of the thickness of the host rock, with one restriction, namely, that an extremely thick dolomitic series would probably not fracture as readily and favorably as a thin series, and may on that account be less receptive to ore solutions.

Age of the Deposits.—The problem of the age of the deposits is still in doubt and may never be solved satisfactorily. It is admitted that the lead and zinc occurrences of the North African metallogenic belt range in age from late Precambrian to the post-Alpine orogeny. The Bou Beker-Touissit deposits that lie in the Lias (Lower Jurassic) can be only Jurassic or post-Jurassic.

Until recently, the earliest known movements that could have initiated the metallizing cycle, as well as prepare the Lias structurally by fracturing, were of early Cretaceous age. Consequently, the age of the deposits was considered as no earlier than lower Cretaceous and no younger than late Tertiary (end of Alpine orogeny).

The Cretaceous movements are hardly, if at all, recognizable in the Bou Beker area. Recent geologic work, on the other hand, has demonstrated the existence of an important, formerly unknown, disturbance dating from the end of the Oxfordian. It is further established that the south border fault of the horst of Bou Beker originated at that time through the overlying Jurassic sediments, and that this fault was never afterwards the site of renewed movement.

The south border fault of the horst is also the axis along which the lead-zinc ore bodies are strung out, and it was thus presumably the avenue of access for the mineralizing solutions.

One would normally expect solutions to invade an avenue of access at the time that movement occurs, that is, at the time when the major fracture is formed and reaches into the reservoir of ore solutions. Thus, if the south border fault of the horst, or the fault-axis of the ore deposits, were the only major fault of the area, it could be assumed that the deposits were formed when that fault originated at the end of the Oxfordian, since it did not move again afterwards, and the age of the ore formation would thus be Oxfordian or upper Jurassic.

However, there are many other major faults in the area, all of which apparently moved again in post-Oxfordian time. It is not excluded then that the solutions were tapped in a later period of movement by a fault such as the north border of the horst, for instance, but were, through some interconnecting of fractures at depth, canalized into the pre-existing south border fault.

In short, although the ore deposits may have been formed as early as the upper Jurassic, instead of the early Cretaceous as was formerly believed, it cannot be proved conclusively that they did not form at a later date.

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The list of men who have contributed to the gradual accumulation of the geologic knowledge of the area is long and only a few names can be mentioned here. Scientific homage must be paid first to the late J. Segaud, for a long time chief geologist of Zellidja, whose intuitive vision was responsible in a large measure for the discovery of the large deposits of the area, and whose inspiring leadership in the study of the problems of the area guided his followers into solving many of them. Acknowledgments must be made of valuable studies on Bou Beker by consulting geologists J. K. Gustafson, R. T.

Walker, and J. Goguel. A remarkable regional study of the Jurassic of the Algero-Moroccan border done by G. Lucas of the University of Algiers, and published as Bulletin No. 16 by the Service de la Carte Géologique de l'Algérie, has been and remains a guide and a great source of reliable information for the geologists working on the detailed problems of the area.

Mention must also be made of excellent contributions to the study of the deposits by geologists of the Service Géologique du Maroc, and in particular of the symposium of the Bou Beker-Touissit area presented before the XVIIIth International Geological Congress in London.

The authors gratefully acknowledge that much credit for the present advancement—which this paper attempts to summarize—of the geologic and mineralogical knowledge of the area is also due to the following colleagues and collaborators who were at one time, or are at present, on the geologic staffs of Zellidja and Nord-Africaine du Plomb: A. Landel, W. D. Michell, S. Janiak, and H. Castro.

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March 20, 1952.

OPAQUE MATTER IN COAL.[1]

P. A. HACQUEBARD.

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ABSTRACT.

The polished surface technique is used to study the nature and occurrence of opaque matter in coal. The appearance of the opaque matter under reflected light was determined from a polished, thin section, in which the opaque constituents were first established under transmitted light.

Two distinctly different forms of opaque matter are recognized, namely, fusain lenses and opaque attritus. Based upon the presence or absence of a botanical structure, the opaque attritus is subdivided into two groups of opaque ingredients. For those devoid of structure the term micrinite is used. Micrinite occurs in three forms: finely divided granular, massive, and as groundmass. Opaque attritus with structure consists of fusinite, semifusinite, and sclerotinite (fungal matter).

Evidence for the origin of the opaque matter during the early stages of coal formation is given. A distinction is made between the opaque matter of "primary" origin, and the opacity of high-rank coals, which is due to increased coalification. It is shown that in anthracite the opaque matter of "primary" origin can be recognized under reflected light with the aid of etched, polished sections. No increase in the amount of "primary" opaque matter with increase in rank has been observed.

The percentage of opaque matter is determined with an integrating stage, using polished specimens of ground coal, mounted in lucite. The results are compared with the proximate analyses of the coal investigated. They show that a high percentage of opaque matter corresponds with a high percentage of fixed carbon and usually a high percentage of ash.

Photomicrographs illustrate the paper.

INTRODUCTION.

In bituminous coals and lignites certain coal constituents do not transmit light in thin sections. Thiessen (27) [2] described these consituents as opaque

[1] Published by permission of the Director-General of Scientific Services, Department of Mines and Technical Surveys, Ottawa, Ontario, Canada.

[2] Numbers in parentheses refer to Bibliography at end of paper.

matter and concluded that they are of botanical origin. They are more highly carbonized than the rest of the coal and stand out in sharp contrast on account of their opaqueness. Because opaque matter occurs in different concentrations throughout the section of a coal seam, its amount is used as a basis for determining the different types of coal. For the lower-rank coals the opaque matter can be recognized satisfactorily in thin sections. However, coals of higher rank, such as low volatile and anthracitic coals, are too dense and opaque to transmit light in thin sections. Increase in rank, which is accompanied by an increase in carbon, causes a general opacity of the coal. This poses the problem of the value of opaque matter as a basis for a type classification of coals of all ranks. Unless the opaque matter as observed in the lower-rank coals can still be detected in the higher-rank ones, its amount cannot be properly used as a general criterion for the different types of coal. In this respect, the effect of metamorphism on the amount of opaque matter is also highly important, because the type classification, as suggested by Thiessen, is based upon the origin of the coal (28).

Because the polished section technique of examining coal microscopically may be used regardless of rank, the author is of the opinion that the problems outlined above can best be studied by this method. Moreover, opaque substances in general, reveal details under reflected light, that cannot be observed under transmitted light. In this paper features observed in opaque matter of bituminous coals are described in detail, and illustrations are given of opaque matter in the higher-rank coals. A method to determine the amount of opaque matter under reflected light is presented, and the effect of opaque matter on the proximate analysis of the coal is discussed.

THE DETERMINATION OF OPAQUE MATTER UNDER REFLECTED LIGHT IN BITUMINOUS COALS AND ANTHRACITES.

The appearence of opaque matter under reflected light has been determined with the aid of polished, thin sections of high volatile "A" bituminous coal. In previous publications (5, 6), the author has shown, with photomicrographs, that those constituents which are opaque under transmitted light have the highest reflection indices under reflected light, and consequently appear white. This is illustrated again in Plate 1. In the lower-rank bituminous coals the opaque matter is further characterized by a greater hardness than the other coal constituents, which gives it a greater relief in polished sections. This may be used to advantage in certain cases where it is difficult to recognize opaque matter from vitrinite, which has the next highest reflection index, and which appears under reflected light slightly darker in color than the opaque constituents. The so-called "Becke Test," as used in ordinary petrography, to determine the relative indices of refraction of two minerals lying in contact with each other, is also applicable under reflected light, and is in certain instances a most helpful device for recognition of opaque matter.

In low volatile bituminous coals the physical and optical differences between opaque matter and other macerals are less pronounced. However, by

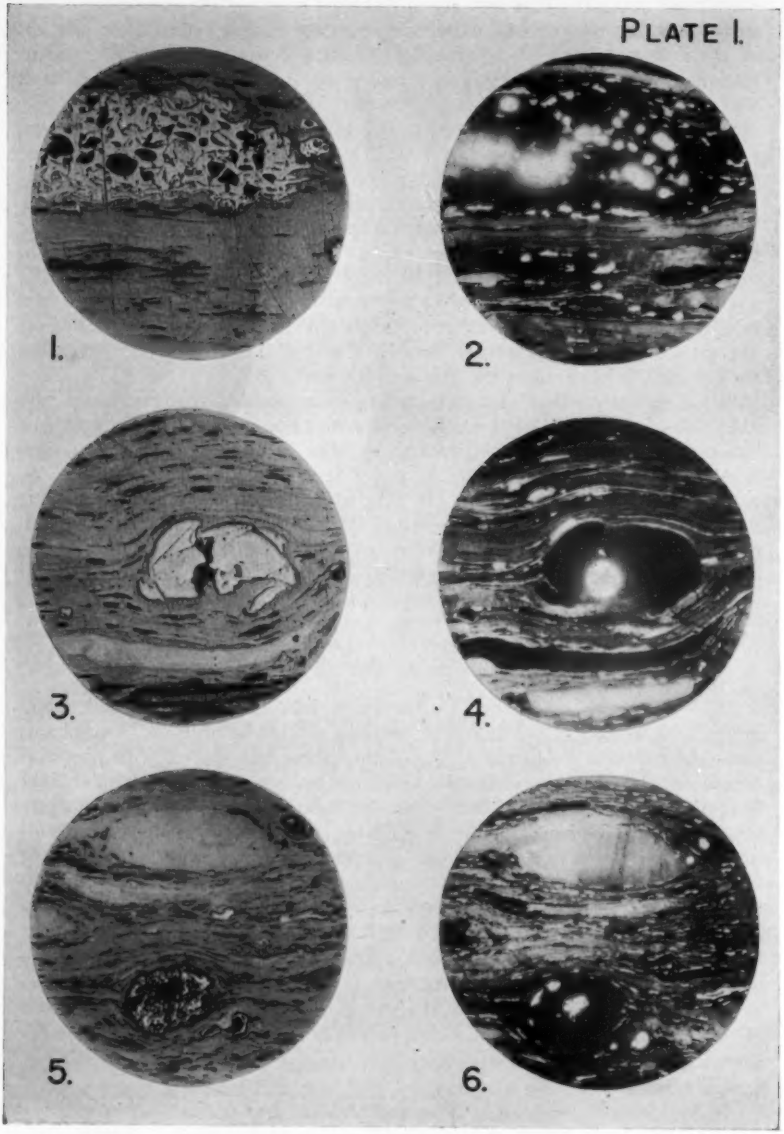
PLATE I.
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6.

using an oil immersion lens the difference in reflectivity can still be observed, and the opaque matter recognized. This method is extensively used by E. Stach and others in Germany, and the results are beautifully illustrated in the "Atlas For Applied Coal Petrography" (1).

In anthracitic coals the physical and optical properties of the different constituents are almost alike. Only by special methods, such as examination with etched, polished sections, or with polarized light through crossed nicols, is it possible to distinguish the macerals of coal as they are known from lower-rank groups. Seyler's (17) method of etching polished sections with a mixture of chromic acid and sulfuric acid is used in this paper. It was found that the acids attack the different constituents in a different degree, and that etching, to a certain extent, gives the anthracitic coals an appearance under reflected light, somewhat similar to that of non-etched, polished sections of lower-rank coals. The spores and cuticles are most severely etched and turn brown or black if the etching is carried out too long. The vitrinite remains light in color, but almost always reveals its cell-structure pattern. The opaque matter is very lightly affected by the etching, and as in the lower-rank coals, appears white in contrast to the darker color of the other macerals, which is accentuated by the etching. Morphological shape and botanical structure are further aids in recognizing opaque matter in etched polished sections of anthracitic coals (Pl. 2).

THE DIFFERENT CLASSES OF OPAQUE CONSTITUENTS IN COAL.

Opaque matter of organic origin occurs in coal in different forms that vary greatly in size and distribution, and that may or may not reveal a cellular structure, or resemble closely botanical entities. Two distinctly different forms of opaque matter are recognized: first, well defined lenticular bodies that

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PLATE I.* OPAQUE MATTER UNDER REFLECTED AND TRANSMITTED LIGHT.

The photomicrographs of Plate I are from a polished, thin section of coal. Each pair are of the same view, those to left were taken under reflected light, those to the right under transmitted light. All are from high volatile "A" bituminous coals.

FIGS. 1, 2. Pittsburgh coal bed, U. S. Experimental Mine, Allegheny Co., Penn. (× 210.)[10] The opaque matter in upper half represents fusinite, with cell cavities empty (or filled with gas); cavities are black in Figure 1 and white in Figure 2. In Figure 1 most cell walls are crushed, known as "bogen structure."

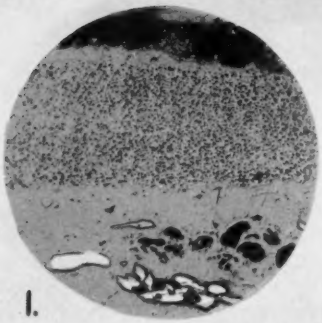
FIGS. 3, 4. Harbor seam, Sydney Mines district, Sydney coalfield, Nova Scotia, Canada. (× 150.) In center is a crushed sclerotioid and elongated strip of opaque matter underneath is semifusinite. Note difference in reflectance between the sclerotinite and semifusinite.

FIGS. 5, 6. Harbor seam, Sydney Mines district, Sydney coalfield, Nova Scotia, Canada. (× 150.) Particles that appear black (opaque) under transmitted light are white under reflected light; these represent granular micrinite. At bottom is a much corroded sclerotioid with marked relief. Oval shaped body near the top is maceral collinite (vitrinite devoid of cellular structure). Under reflected light it is light gray without relief; under transmitted light it has the orange color of anthraxylon, without cellular structure.

* All pictures illustrated are from original photographs taken by the author and M. S. Barss, Technician, Fuels Resources Division, Geological Survey of Canada.

[10] The magnifications indicated are those of original views, which have been reduced by ⅓.

PLATE 2.



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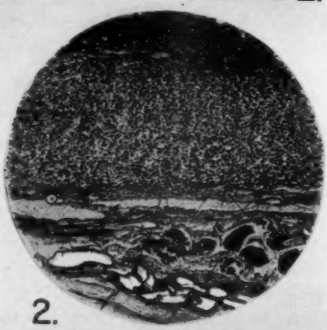

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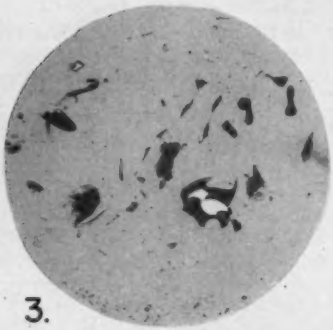

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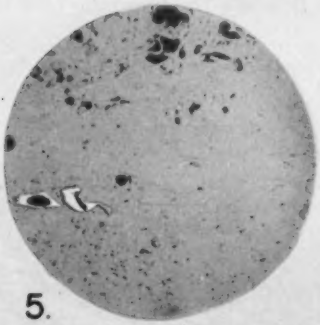

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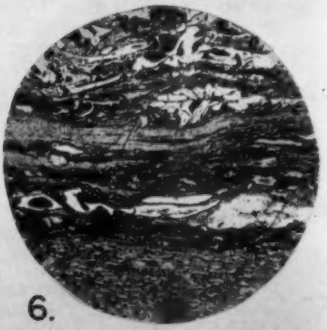


6.

generally can be separated easily from the rest of the coal, and secondly, finely macerated particles, intimately mixed with the other coal ingredients. The former constitute fusinite lenses, which are considered to be the rock type, or banded ingredient fusain, when they are 1 mm or more thick, measured across the bedding plane (5). The latter were designated by Thiessen (27) as opaque attritus. The opaque attritus, which occurs in high concentrations in splint coals, is divided by Thiessen (28) into two classes of opaque constituents, namely, semi-translucent or brown matter and finely divided, or granular opaque matter. These terms are entirely descriptive and do not reveal any relation to botanical structures, which under transmitted light cannot be detected very easily.

However, studies under reflected light, carried out in Germany, and by the author, show that opaque attritus contains certain ingredients that have retained their original plant structure. It was found that several macerals of coal, as formulated by Stopes (24), constitute part of the opaque attritus. These are: fusinite, semifusinite, and sclerotinite (10, 26). Those ingredients of opaque attritus that are devoid of structure represent the maceral micrinite.

The above mentioned classes of opaque constituents in coal are summarized in Table I, and are discussed in detail in the following paragraphs.

TABLE I.

CLASSIFICATION DIAGRAM OF OPAQUE CONSTITUENTS IN COAL.

- Opaque matter in coal
  - Fusain
    - Soft variety
    - Hard variety
  - Opaque attritus
    - With botanical structure
      - Fusinite
      - Semifusinite
      - Sclerotinite
    - Devoid of botanical structure
      - Micrinite
        - Granular
        - Massive
        - Groundmass

PLATE II. "PRIMARY" OPAQUE MATTER IN ANTHRACITE.

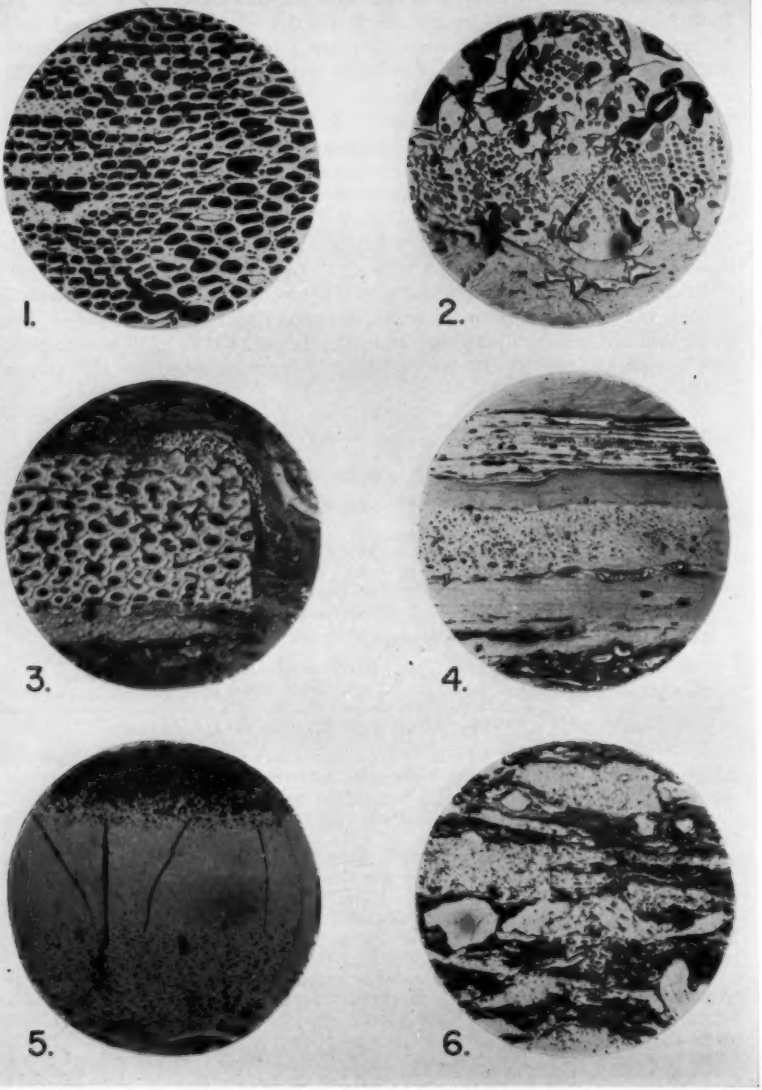
The photomicrographs of Plate II are taken under reflected light from polished anthracite, those on the left are non-etched and those to the right are the same views after etching the coal for 1½ minutes in boiling chromic-sulfuric acid. All illustrations are from seam Merl, Domaniale Mine, South Limburg coalfield, Netherlands (V.M.: 8.44 percent).

FIGS. 1, 2. Upper half "primary" opaque matter is fusinite, white angular particles below are micrinite. They possibly could represent broken cell walls (fusinite) or fragments of sclerotiods (sclerotinite). The material in between is vitrinite (thin, light-colored band underneath the fusinite), exinite (dark-colored ingredients) and possibly sclerotinite (tissue with irregular cellular structure in bottom right of photographs). (× 150.)

FIGS. 3, 4. White material in center is interpreted as fungal tissue, and consequently represents sclerotinite. Underneath it are four micrinite granules and at bottom is fusinite. Note thin, light-colored vitrinite bands and dark-colored spore material (exinite). Note how etching exposes opaque matter, and other coal constituents in anthracite. (× 150.)

FIGS. 5, 6. White particles and splinters in center are considered as micrinite. The white ingredients near top are mostly sclerotinite. At bottom, there is a layer composed of semifusinite. (× 150.)

PLATE 3.



Fusain.—Fusain occurs in lenses or irregular wedges lying on bedding planes at various angles. It has a typical fibrous structure, is very friable, and breaks down to a soiling black powder. It resembles charcoal in appearance. The lenses vary in thickness from 1 mm to about 2 inches, and can usually be separated easily from the rest of the coal. Under the microscope, fusain is of simple composition, inasmuch as it consists essentially of the same material throughout. This material consists of the coalified walls of cellular tissue which, unless disturbed by pressure, has retained its original pattern. It represents the maceral fusinite, as defined by the Heerlen, 1935, Round Table Conference (8). The fusinized tissues are characterized by the absence of organic material inside the cell cavities. In the so-called soft fusain, these cavities remained empty, or became filled with gas. When filled with mineral matter, such as for instance pyrite or calcite, the fusain is hard and is termed hard fusain (Pl. 3, Figs. 1, 2).

Fusain occurs predominantly in bright coal varieties, and may occur throughout the entire section of a seam. Regionally, its amount within any seam varies to an appreciable extent, although certain intervals of the seam which are relatively high in fusain may be traced for several miles. Regional variations of the amount of fusain in seams of different rank, and from different coalfields, are shown in Table II. From this table it appears that the fusain content of coal is independent of its rank. As fusain is found in coals

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PLATE III.* FUSAIN, FUSINITE, AND SEMIFUSINITE.

FIG. 1. Harbor seam, Sydney coalfield, Nova Scotia, Canada.† (× 150.) Soft fusain with empty (or gas-filled) cell cavities. Note woodcell structure with intercellular spaces. View is part of a fusain lens of 5 mm thickness and opaque (white) cell walls represent maceral fusinite.

FIG. 2. No. 2 seam, International Mine, Coleman, Alberta, Canada. Medium volatile bituminous coal of Lower Cretaceous age. (× 150.) Hard fusain with calcite in cell cavities. Note disturbed cellular structure near top.

FIG. 3. Harbor seam, Sydney coalfield, Nova Scotia. (× 150.) Fusinite in transverse section through a fusinized twig. Note wood tracheids with middle lamellae and plasmodesmata (minute channels through the cell walls). Underneath is semifusinite and another fragment of fusinite is curved around it near the top.

FIG. 4. Pittsburgh coal bed, U. S. Experimental Mine, Allegheny Co., Penn.† (× 130.) This shows the difference in reflectance between fusinite (near the top), semifusinite (in center), and vitrinite (in between). The fusinized tissue represents a tangential section through a small twig. Note that in the semifusinite only part of the cell cavities are empty.

FIG. 5. Harbor seam, Sydney coalfield, Nova Scotia, Canada. (× 100.) Transition between fusinite (top and bottom), semifusinite (adjoining fusinite) and vitrinite (in upper half). The fusinite at the top was too soft to be polished and therefore completely absorbed the light. Note cracks in vitrinite, which seem to indicate that it is not as strong under pressure as the opaque matter.

FIG. 6. Harbor seam, Sydney coalfield, Nova Scotia, Canada. (× 150.) An illustration of fragments of semifusinite in durain, surrounded by exinite and micrinite.

* Unless stated otherwise, all pictures of Plates 3–6 are taken under reflected light from non-etched polished sections, without using the oil immersion lens.

† All coal seams of the Sydney coalfield and the Pittsburgh coal bed of U. S. Experimental Mine, Allegheny County, Pennsylvania, are high volatile "A" bituminous coals of Pennsylvanian age.

TABLE II.

PERCENTAGE OF FUSAIN IN SEAMS OF DIFFERENT RANK.

Name of seam	Coalfield	Country	Rank		Percentage of fusain in different samples[3]	Average % of fusain
4 Lignite seams[7]	North Dakota	U. S. A.	Lignite		6 1 3 6	4
Harbor	Sydney	Canada	High volatile "A"	Bituminous coal	3 3 3 2 2 1 4 1 2 3	3
Boutilier	Sydney	Canada			7 16 13 8 13	11
Backpit	Sydney	Canada			4 8 5 10 9 6 9 7 9 9	8
Phalen	Sydney	Canada			5 2 3 2 6	4
Grauweck[4]	South Limburg	Netherlands	Medium volatile		9 7 7 5 6	7
Merl[5]	South Limburg	Netherlands	Low volatile		11 10 12 7 5 11 7 10 11 7	9
Steinknipp[5]	South Limburg	Netherlands			19 12 14 13 10 17 14 11 7 13	13
Finefrau A[6]	South Limburg	Netherlands	Anthracite		3 5	4
Finefrau B[6]	South Limburg	Netherlands			14 9	12
Finefrau C[6]	South Limburg	Netherlands			11 8	10
Senteweck	South Limburg	Netherlands	From medium volatile to semi-anthracite		3 7 2 5 3 11 8 3 6 4	5

[3] Samples represent complete section of seam and were taken over the entire coalfield, unless stated otherwise. The distance between samples varies from 1 to 3 miles.

[4] Samples from S. M. Maurits.

[5] Samples from O. N. Mines and mines farther east.

[6] Samples from Willem Sophia and Domaniale Mines.

[7] Figures taken from B. C. Parks (12).

Figures pertaining to seams Grauweck and Senteweck were taken from A. L. F. J. Maurenbrecher (11).

Figures pertaining to seams Merl, Steinknipp, and Finefrau A, B, and C are taken from P. A. Hacquebard (4).

of all ranks and occurs also in peat, there is no apparent relation between the degree of metamorphism of the coal and its amount of fusain. This is further illustrated graphically in Figure 1, showing the variation of fusain content in two seams, of which the Backpit seam of the Sydney coalfield is almost constant in rank, whereas the Senteweck seam of the South Limburg coalfield of the Netherlands is variable. In both seams the fusain content has been determined in ten complete channel samples, which are spaced at regular intervals over the entire coalfields. Because Figure 1 shows plainly that the

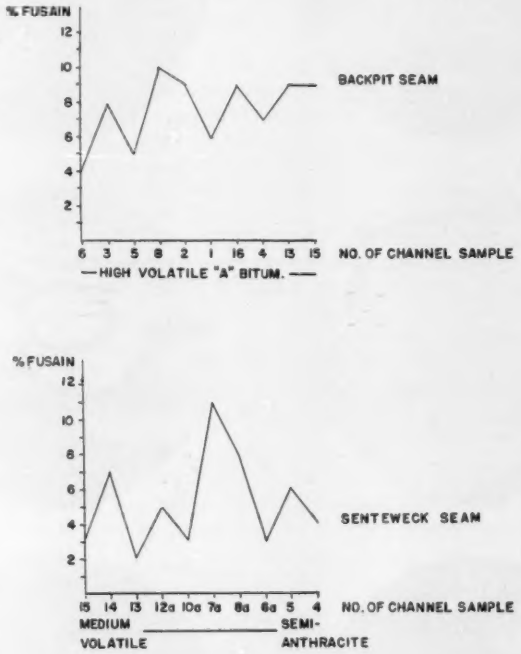

FIG. 1.

variations in the percentage of fusain occur irrespective of the rank of the seam, it is concluded that fusain probably originated during the early stages of coal formation, and very likely before burial by overburden.

Several theories on the origin of fusain in a peat swamp have been advanced and were discussed by the author in a previous publication (4). That one specific cause alone is responsible for the formation of fusain seems highly improbable. It appears more likely that several of the current theories, as for instance, forest fires and partial submergence of vegetable debris, all played an important part in the origin of fusain.

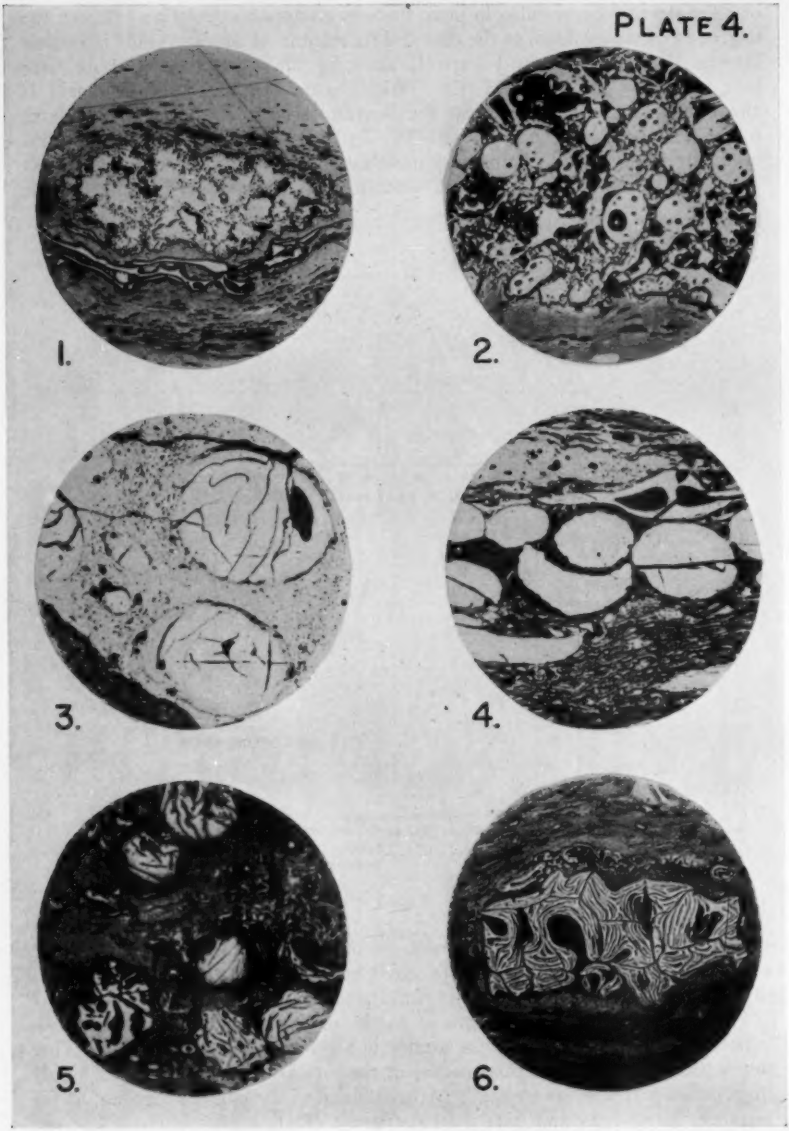
PLATE 4.
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The fusinization of plant material causes a concentration of carbon and elimination of oxygen and hydrogen, which makes fusain opaque in the lower-rank coals where other coal constituents are transparent. The chemical composition of the high-rank coals closely resembles that of fusain, and these coals are accordingly completely opaque. However, this opacity was largely caused by metamorphism, which affected predominantly the transparent constituents of the lower-rank coals. In other words, opaqueness in coal is caused by two different processes, which affected the organic material either at the inital stage of coal formation, or later during the metamorphic changes. The former may be designated as "primary" opaque matter to differentiate it from "secondary" opaque matter due to metamorphism. "Secondary" opaqueness starts in the medium volatile coals, at about 23–25 percent volatile matter, and rapidly increases when coals of anthracitic rank are approached (15). The original botanic structure of those constituents that are affected by secondary opaqueness (vitrinite and exinite) can still be detected with the aid of etched polished sections (14) (Pl. 2). The changes that occur in coals with from 23–25 percent volatile matter are, in the author's opinion, merely physical and chemical, and do not, as advanced by Schopf (15), alter the botanical pattern of the macerals involved.

Fusinite.—The opaque cell walls present in fusain constitute the maceral fusinite. Besides being present in fusain lenses, fusinite also occurs finely dispersed in the coal and usually is an important component of durain. However, unlike fusain, it cannot be separated readily from the rest of the coal. It is found in fragments (smaller than 1 mm), which show beautifully preserved cellular structure, or it is present in small particles, which may represent broken and separated cell walls. (Pl. 3, Figs. 3, 4; Pl. 4, Fig. 1; Pl. 6, Fig. 4.)

PLATE IV. SCLEROTINITE.

FIG. 1. Pittsburgh coal bed, U. S. Experimental Mine, Allegheny Co., Penn. (× 150.) Fungal tissue with irregular cell structure pattern, cell wall material underneath is fusinite.

FIG. 2. Pittsburgh coal bed, U. S. Experimental Mine, Allegheny Co., Penn. (× 300.) Fungal tissue with sclerotioids, which form a genetic part of the fungal structure.

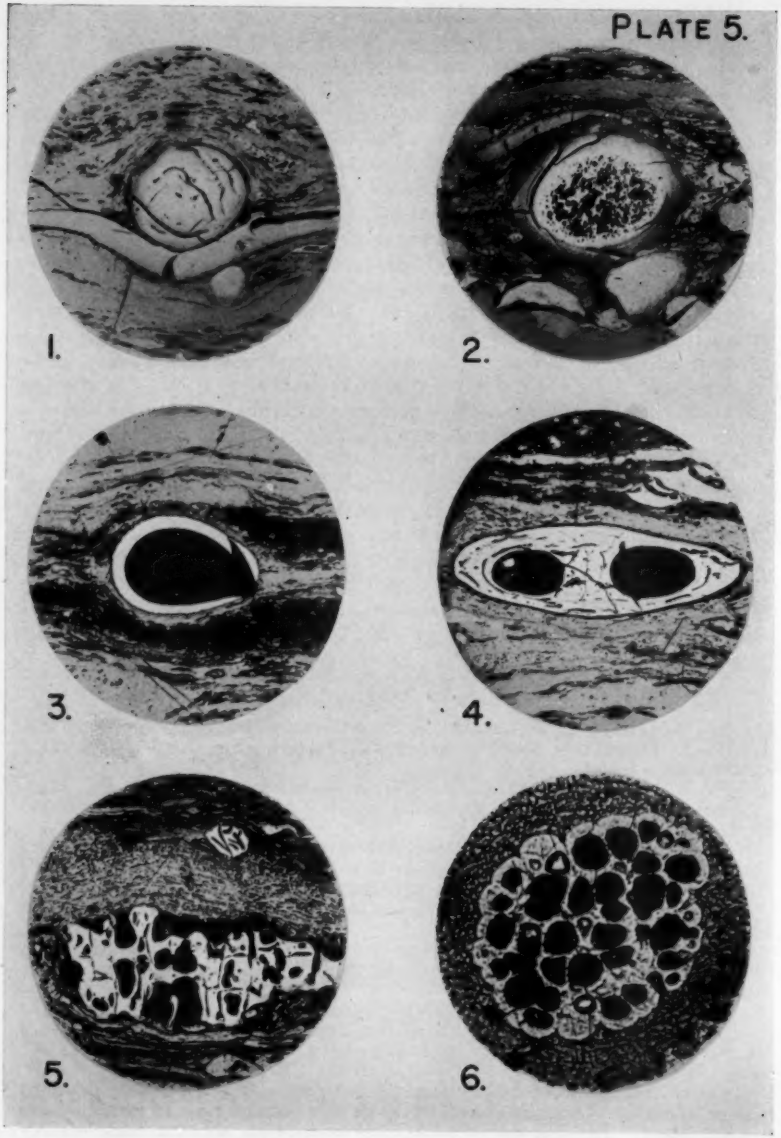
FIG. 3. Lower Jubilee seam, New Waterford district, Sydney coalfield, Nova Scotia, Canada. (× 110.) Sclerotioids in semifusinite, indicating a relationship between these "fungi" and wood. It appears as if the sclerotioids have destroyed parts of cellular structure of the original wood, suggesting they may represent wood-destroying fungi.

FIG. 4. Harbor seam, Sydney Mines district, Nova Scotia, Canada. (× 150.) Round and oval-shaped, smooth-walled sclerotioids, occurring like a colony, in one layer of the coal.

FIG. 5. No. 5 seam, St. Rose coalfield, Nova Scotia, Canada. High volatile "C" bituminous coal. (× 150.) Numerous sclerotioids preserved in the No. 5 seam. Note their peculiar carving, and the high shale content (black particles) associated with them.

FIG. 6. Harbor seam, Sydney Mines district, Nova Scotia, Canada. (× 100.) Large sclerotium with characteristic structure of a compact mass of fungal hyphae (white lines). The thin curved white lines immediately above it could possibly represent fungal hyphae in an initial stage of the formation of sclerotia.

PLATE 5.



According to Seyler (18), fusinite shows the highest reflectance of all coal constituents, and as such is usually easily recognized. However, when present in extremely small particles, fusinite and micrinite cannot be separated under ordinary microscopic examination, and it is quite possible that much of the material classed as micrinite represents fusinite in finely disseminated form. Reflectivity measurements, such as carried out by Seyler, could possibly prove to be of help in determining the identity of the finely divided opaque matter.

Semifusinite.—Material intermediate between fusinite and vitrinite is termed semifusinite (8). It is characterized by a generally well preserved cellular structure, that differs from fusinite structure, inasmuch as some of the cell cavities are filled with carbonized organic matter. Under transmitted light it is semi-opaque in bituminous coals, and possibly represents part of Thiessen's semi-translucent or brown matter. The reflective power of semifusinite is lower than that of fusinite, but a little higher than the reflectance of vitrinite (Pl. 3, Fig. 4). It is considered as a separate maceral because it occurs not only in transition zones between fusinite and vitrinite, but is also present in well defined units surrounded by other coal constituents (Pl. 3, Figs. 5, 6). Like fusinite, it is commonly an important component of durain and fusain. When it is present in lenses or layers thicker than 1 mm it may be considered as a separate rock type, which is named semifusain.

Semifusinite is present in coals of all ranks, and its microscopic appearance

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PLATE V. SCLEROTINITE.

FIG. 1. Harbor seam, Sydney Mines district, Nova Scotia, Canada. (× 140.) This illustrates the great hardness of the sclerotioids, which probably were affected very little by compaction from peat to coal, which caused the vitrinite groundmass and the microspores to become curved around the sclerotioid. The opaque stick (probably fusinite) immediately underneath it was apparently less flexible than other constituents, and like the sclerotiod is very hard. It broke in two at the very place where the sclerotiod exerted its greatest pressure during the coalification process.

FIG. 2. Harbor seam, Sydney Mines district, Nova Scotia, Canada. (× 150.) A sclerotioid showing what may possibly be cellular structure, and solid ring around the main body. As in Figure 1, the vitrinite and exinite are curved around the sclerotioid.

FIG. 3. Harbor seam, Sydney Mines district, Nova Scotia, Canada. (× 150.) Possibly the solid ring around a sclerotioid, similar to the one in Figure 2. However, this picture could also represent the sclerotesta or hard coat of a seed, only its size (230 × 160 microns) appears too small.

FIG. 4. Phalen seam, New Waterford district, Nova Scotia, Canada. (× 90.) Probably a very large sclerotium (770 × 240 microns) showing two big cavities. This is the largest sclerotium seen by the author.

FIG. 5. Merl seam, Domaniale Mine, South Limburg coalfield, Netherlands. Anthracite with 8.44 percent volatile matter of Carboniferous age. (× 150.) View of an etched, polished section of coal under reflected light, illustrating a carved sclerotioid in the upper half, and probably fungal tissue in the lower half. Both features were also discernible in the non-etched section, but the semifusinite and exinite were not.

FIG. 6. Hot Spring County, Arkansas, U.S.A. Tertiary lignite (Eocene). (× 700.) The sclerotium closely resembles *Sclerotites brandonianus*, which Stach (23) observed in Tertiary lignites from Columbia and Hungary. It may possibly represent a guide fossil for Tertiary coals.

indicates that its origin is closely connected with that of fusain. Only the carbonization of the plant material that turned into semifusinite has been less severe than in the material that gave rise to fusinite. As in fusinite, it is believed that this carbonization took place during the peat stage.

Sclerotinite.—The term sclerotinite, to describe the fungal matter in coal, has been introduced by Stach (1). At the Second Round Table Conference on Coal Petrography, held in June 1951, in Heerlen, Holland, the proposal to add sclerotinite as a new maceral of coal has been adopted (10, 26). Fungal matter in coal is represented as fungal tissues, sclerotia, or fragments of sclerotia. It occurs in coals of all ranks and of different ages (16, 22, 23). Sclerotinite has been described and well illustrated by Stach in his Textbook on Coal Petrography (23), and more recently in the Atlas for Applied Coal Petrography (1). Most of the following information has been obtained from this literature and from the author's own observations.

Fungal tissue is characterized by its irregular size and the abnormal pattern of its cellular structure. The tissues are considered to represent fungal hyphae and under the microscope are somewhat similar to semifusinite, because their reflective powers are very much alike (Pl. 4, Fig. 1). It occurs in isolated fragments or closely connected with semifusinite, fusinite, and vitrinite. In other words it occurs with the coal constituents that are related to woody parts of the original vegetation.

The sclerotia, for which the maceral has been named, were first observed in Tertiary lignites and Mesozoic coals (7, 20, 21) (Pl. 5, Fig. 6). Although probably present in almost every coal of Carboniferous age, they were not recognized as such until 1933, when Schulze (16) was able to establish their identity. Most of the Carboniferous "sclerotia" are ball-shaped and show, as a rule, no discernible structure. For this reason, several investigators, for instance Duparque (2) and Fanshawe (3), have interpreted them as resin globules. However, in thin sections of bituminous coals resin globules appear in a transparent, bright yellowish color, whereas the ball-shaped features under discussion do not transmit light, and are definitely opaque (Pl. 1, Figs. 3, 4, 5, 6, and illustrations that accompany the literature cited under 5 and 6). They are further characterized by a great hardness, that causes a very pronounced relief in the polished sections, which is greatly unlike the resin globules, which show hardly any relief whatsoever (Pl. 5, Fig. 1).

Because the ball-shaped features show a certain likeness with sclerotia, but in most cases do not reveal the typical structure of the fungal hyphae, the author has suggested use of the term "sclerotioids" (6). Only when the structure can be observed plainly is it justified to use the term sclerotium (Pl. 4, Fig. 6; Pl. 5, Fig. 6).

The sclerotioids occur in separated form scattered through the coal, in colonies, or within semifusinite and fusinite. They vary in size between 40 and 770 microns, and are smooth-walled or carved, or show a peculiar cellular structure (Pl. 4, Figs. 4, 5; Pl. 5, Figs. 1, 2, 3, 4). Where present in semifusinite or fusinite, their relation to the cellular structure is most instructive. As may be seen in Plate 4, Figures 2 and 3, the sclerotioids form an integral part of the carbonized tissue, but have destroyed the original cellular structure

in their immediate vicinity. This leads to the belief, as was first suggested by Schulze (16), and later affirmed by Stach (23), that the sclerotioids represent the remains of wood destroying fungi.

Although commonly a minor component of coal, certain seams may carry tremendous amounts of sclerotioids, as was found by the author in the No. 5 seam of the Saint Rose and Chimney Corner coalfields of Cape Breton Island, Nova Scotia, Canada (6). As many as 2,600 sclerotioids per square inch were counted in polished sections, cut across the bedding plane, in certain intervals of this seam. Where present in such great quantities it could be established that they have a favorable effect on the percentage of fixed carbon, and caused this high volatile "C" bituminous coal to burn almost like anthracite.

Because the sclerotioids have been found closely connected with semifusinite and fusinite, and are present in coals of all ranks, it appears evident that they originated during the peat stage. Fungal action in swamps is certainly not extraordinary. The fact that when present in great numbers the ash content of the coal is very high (6) might possibly indicate that subaquatic conditions were not favorable for these fungi, which therefore turned into the dormant state of the sclerotia.

Micrinite.—The term micrinite should be reserved for opaque attritus which is devoid of structure. It is not equivalent to the general term opaque matter, in which sense the author has mistakenly used it before (5).

At the Second Round Table Conference, held in June 1951 (10, 26) the proposal put forward by the German coal petrographers, to distinguish between granular and massive micrinite, was accepted. However, the term massive is not clearly defined. It could mean either one solid, fairly large patch of opaque matter, or several particles closely packed, giving a compact, or massive appearance. The latter interpretation appears to be the one used in the Atlas for Applied Coal Petrography (1).

Besides granular and massive, the author believes that micrinite rarely occurs as a groundmass in which the other macerals (mostly exinite) are embedded. The term groundmass, as used here, is considered as a bond or matrix that holds other components together. This meaning differs substantially from the one used in the Atlas for Applied Coal Petrography. According to this Atlas, the macerals of coal may be divided into two groups. The first group, which is considered as the groundmass of the coal, is composed of the macerals vitrinite, semifusinite, fusinite, sclerotinite, and micrinite; in other words of the opaque attritus. The second group constitutes the macerals exinite and resinite, which are considered as inclusions in the groundmass.

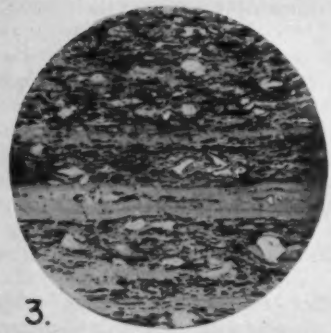
A groundmass, according to the author's conception, may commonly be amorphous. If crystalized, or composed of well defined particles, it is generally of a uniform and finely-grained texture, as for instance in certain igneous rocks, like porphyries. In porphyries, the larger crystals are known as phenocrysts, and the finer-grained material as the groundmass of the rock. These conditions are not encountered in coal, where the opaque matter may be either larger or smaller than the macerals exinite and resinite.

Therefore, it might be better to restrict the usage of the term groundmass

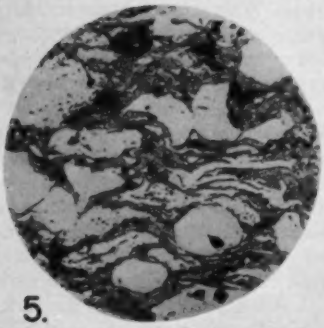
PLATE 6.

1.

2.


3.

4.


5.

6.

to a bond or matrix in which the other constituents are embedded. The maceral that generally forms the groundmass in coal, in this sense, is vitrinite.

With the aid of the photomicrographs, illustrated on Plate 6, the different forms of micrinite are discussed.

Granular micrinite is composed of finely divided granules, angular shaped particles, and splinters. The finely divided granules (Pl. 6, Figs. 1, 2) commonly form a most important ingredient of certain splint coals or durains. Their origin, according to Thiessen and Sprunk (29), is due to the disintegration of the secondary walls of the tracheids of wood cells. This disintegration takes place in an advanced state of decomposition of the plant material, and is caused by biological agencies.

The angular shaped particles and splinters (Pl. 6, Figs. 3, 4) may represent broken and separated cell walls or parts of fungal matter. In other words, small fragments of the macerals fusinite and sclerotinite. Because their identity as such often cannot definitely be established, these fragments are classed as micrinite.

Granular micrinite occurs most abundantly in the dull coal varieties (clarodurain and durain). The non-banded coals, such as boghead and cannel coals, generally contain micrinite in granular form. It is for this reason that its origin is believed to be closely connected with these coals, which most likely were laid down under sub-aquatic conditions (1, 25).

Massive micrinite is represented in coal by opaque particles or flakes closely packed and giving a compact or massive appearance (Pl. 6, Fig. 5). It is typical of many durains. The botanical identity of this material has as yet not been established. Consequently, its origin is a matter of speculation. According to the Atlas for Applied Coal Petrography, durains characterized by massive micrinite may have been formed in the peat swamp under partial

PLATE VI. MICRINITE.

FIG. 1. Tracy seam, Port Morien district, Nova Scotia, Canada. (× 150.) Finely divided granular micrinite with granules embedded in a groundmass of vitrinite. The bean-shaped gray bodies are spores.

FIG. 2. Tracy seam, Port Morien district, Nova Scotia, Canada. (× 150.) Photomicrograph under transmitted light from coal illustrated in Figure 1, but not the same view. The granular micrinite or granular opaque matter (black) does not appear so well defined in individual granules as in Figure 1. The oval-shaped white bodies in the center are spores (possibly isospores) which in this coal are usually found together with the granular micrinite.

FIG. 3. Pittsburgh coal bed, U. S. Experimental Mine, Allegheny Co., Penn. (× 150.) Granular micrinite present in small angular shaped particles scattered throughout the coal, embedded in a groundmass of vitrinite.

FIG. 4. Pittsburgh coal bed, U. S. Experimental Mine, Allegheny Co., Penn. (× 150.) Granular micrinite in splinters and particles that may possibly represent broken cell walls and fragments of sclerotioids. Because the identity of this material as fusinite and sclerotinite cannot definitely be established, it is considered as micrinite. Note semifusinite in the upper half of picture.

FIG. 5. Harbor seam, Sydney Mines district, Nova Scotia, Canada. (× 210.) Massive micrinite, composed of closely packed opaque particles and flakes, in a groundmass of exinite. Some particles of semifusinite are present.

FIG. 6. Harbor seam, Sydney Mines district, Nova Scotia, Canada. (× 210.) Exinite in a groundmass of micrinite.

access of air. This view is supported by the observation that massive micrinite generally occurs together with semifusinite and fusinite.

As *groundmass,* micrinite occurs occasionally in very dense durains, where, together with exinite, they may form the sole constituents (Pl. 6, Fig. 6). Because durains of this type are always high in ash, it is believed that they originated under sub-aquatic conditions. However, the actual mode of origin of the opaque groundmass, and the kinds of plant tissues from which it is derived, are not known. The material is devoid of cellular structure; at least with ordinary microscopic examination, no structure has been observed.

QUANTITATIVE MICROSCOPIC MEASUREMENTS OF OPAQUE MATTER IN COAL.

The method of using an integrating stage to determine the percentage of the banded ingredients in ground coal, as introduced by Kühlwein in 1934 (9), is adopted for the quantitative measurements of the coal macerals.

The coal to be examined, either from a storage pile, or from a specific petrographic interval of the seam, is first carefully ground to below 0.5 mm (32 mesh). The grinding should be carried out carefully in order to obtain particles of about equal size. After grinding, the sample is quartered down to about 3 or 4 grams, which are mixed with twice the amount of lucite powder (a transparent plastic material). This mixture is molded into a pellet with a mounting press under elevated pressure and temperature (3,000 lbs. per sq in and 130° C).

The pellet is examined under reflected light at a magnification of about 300 times, and with the aid of the integrating stage the percentages of the different constituents are determined. These constituents are: vitrinite, exinite, opaque attritus (fusinite, semifusinite, sclerotinite, and micrinite), and the visible mineral impurities, like carbonaceous shale, pyrite, calcite, etc. With opaque attritus are included fragments of hard fusain, that became broken during the grinding. Soft fusain, upon grinding, immediately turns into an extremely fine powder, which is very difficult to recover completely. It is for this reason that the percentage of soft fusain is determined from the polished sections that cover the same petrographic interval of the seam as the pellet.

If it is required to obtain accurate figures on the percentage of pyrite and shale, the following method is used. The original sample, after grinding below 32 mesh, is separated into a light and a heavy fraction, for which a solution with a specific gravity of 1.6 is used. The heavy fraction will then contain most of the visible mineral impurities. From both fractions, separate pellets are made, and more accurate figures on the percentage of pyrite and shale can be determined than if only one pellet of the original sample had been prepared. However, for the quantitative analyses of petrographic subdivisions of a coal seam, one pellet is generally considered sufficient. It was found, that the regional differences in comparable intervals of different samples show variations, that do not always justify the extra time involved in the examination of two pellets, which is needed for a slightly greater accuracy.

The great advantage of the method outlined here is the fact that it is

comparatively simple to carry out, and further, that it is far less time-consuming and tiresome than other methods currently in use.

THE EFFECT OF OPAQUE MATTER ON THE PROXIMATE ANALYSIS OF COAL.

With the method previously discussed, quantitative microscopic measurements were made of the major coal components of several petrographic intervals of the Tracy seam of the Sydney coalfield. The coal of this seam is characterized by a relatively high percentage of opaque matter, which consists predominantly of fusain lenses and granular micrinite (Pl. 6, Figs. 1, 2). Together with micrinite, a peculiar type of spore, in size intermediate between mega- and microspores, and possessing an unusually hard exine, that gives it a high relief in polished surfaces, is found throughout the section of this seam. The occurrence of these spores in combination with granular micrinite is unique for the Tracy seam. So far it has not been observed in any of the other seams of the Sydney coalfield. Due to this peculiar feature, which is present almost throughout the entire section of the seam, and which could be traced regionally over 8 miles, the author believes that even from a small, odd block of coal, the Tracy seam may be identified. Although the spores are present in great numbers, the percentage figure of exinite in the different petrographic intervals of the seam remains low. It varies between 2 and 8 percent.

The petrographic composition of six different intervals of the Tracy seam, expressed in percentage by weight on shale- and pyrite-free coal, is illustrated in Table III. The corresponding proximate analyses of the intervals examined are also indicated. With the aid of the Parr formulae (13), the fixed carbon is calculated on a mineral-matter-free coal basis. A comparison of the fixed carbon figures thus computed, with the total opaque matter, shows that undoubtedly there exists a relationship between the two. When the intervals are high in total opaque matter, they generally show a correspondingly high figure for fixed carbon. This figure may be lowered some, due to a relatively high percentage of exinite, as is the case in interval X. However, a linear relationship between opaque matter and fixed carbon does not occur, which is due to the fact that fixed carbon is merely a calculated figure, that does not express the total carbon that is present in the coal. Unfortunately, the author has as yet not been able to obtain figures on total carbon, for which an ultimate analysis of the coal is required.

In Table IV, the results of a number of analyses are illustrated, which pertain to selected samples from the St. Rose and Chimney Corner coalfields, Cape Breton Island, Nova Scotia, Canada. These samples have been described previously (6), and have been selected for their different concentrations of sclerotioids (Pl. 4, Fig. 5). They belong to two different seams, namely the No. 5 seam (Nos. CC 1 and SR 1) and the No. 2 seam (No. SR 2), which are of the same rank, namely high volatile "C" bituminous coal. The opaque matter in all samples consists predominantly of sclerotioids, together with a minor amount of granular micrinite. The relationship between opaque matter and fixed carbon is essentially the same as in Table III. This in effect

TABLE III.

ANALYSES OF PETROGRAPHIC INTERVALS OF TRACY SEAM, SYDNEY COALFIELD, NOVA SCOTIA, CANADA.

Petrographic interval		Petrographic composition[a]					Proximate analyses[b]			
								Dry basis		
Number	Thickness (inches)	Vitrinite (percent)	Exinite (percent)	Opaque attritus (percent)	Fusain (percent)	Total opaque matter (percent)	Fixed carbon, min.-matter free (percent)	Fixed carbon (percent)	Ash (percent)	Sulfur (percent)
VI	6.8	81	5	14	—	14	61	54.82	8.28	5.10
XI	9	76	4	8	12	20	63	57.78	5.66	5.74
VIII	9.3	67	5	28	—	28	64	59.45	4.40	3.45
IX	9.3	69	2	14	15	29	65	58.66	6.84	6.63
X	0.5	44	8	48	—	48	71	66.28	5.74	2.00
XII	3.6	55	4	12	29	41	72	45.26	29.42	14.30

[a] Petrographic composition expressed in percentage by weight on shale- and pyrite-free coal. Specific gravity: vitrinite 1.3; exinite 1.2; opaque attritus 1.4; fusain 1.5.

[b] These figures were kindly supplied by Mr. M. Bates, Analytical Engineer, Chemical Laboratory of DOSCO, Glace Bay, Nova Scotia, Canada.

TABLE IV.

ANALYSES OF SELECTED COAL SAMPLES FROM ST. ROSE AND CHIMNEY CORNER COALFIELDS, NOVA SCOTIA, CANADA.

Polished section		Petrographic composition[a]					Proximate analyses[b]			
								Dry basis		
Number	Thickness (inches)	Vitrinite (percent)	Exinite (percent)	Opaque attritus (percent)	Fusain (percent)	Total opaque matter (percent)	Fixed carbon, min.-matter free (percent)	Fixed carbon (percent)	Ash (percent)	Sulfur (percent)
CC 1–A18	2	91	4	5	—	5	55	45.87	14.75	3.30
SR 1– 21	1.5	84	2	11	3	14	60	56.17	4.70	4.68
SR 1– 26 & 27	2.9	76	6	17	1	18	60	53.56	8.34	5.64
SR 1– 29	1.5	59	5	36	—	36	64	52.73	13.54	8.32
SR 1– 38	1.5	59	6	35	—	35	66	57.62	10.57	5.74
SR 2– 15	1	48	2	50	—	50	70	48.50	24.85	12.32

is further proof that the sclerotioids indeed may be considered a part of the opaque matter in coal.

The results from both investigations are in accordance with observations made by Sprunk et al. (19), who noticed that the total carbon of splint coals is higher than that of associated bright coals. This was explained by the higher content in opaque matter of the splint coals. However, the amount of opaque matter present in these coals was not given.

To further verify the accuracy of quantitative microscopic measurements of the coal components, as outlined in this paper, it is intended to have ultimate analyses made of the samples investigated, in order to compare the percentage of total carbon with the percentage of opaque matter. It appears to the author that comparative studies in general, between petrographic and chemical analyses of coal, are of the utmost importance, and should be more actively pursued.

GEOLOGICAL SURVEY OF CANADA,
COAL RESEARCH DIVISION,
SYDNEY, NOVA SCOTIA, CANADA,
January 22, 1952.

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ABNORMAL COPPER, LEAD, AND ZINC CONTENT OF SOIL NEAR METALLIFEROUS VEINS.*

LYMAN C. HUFF.

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ABSTRACT.

Samples of normal soils, and soils near metalliferous veins were tested to investigate the behavior of copper, lead, and zinc during the formation of residual soil. The copper, lead, and zinc content of unmineralized bed rock ranges from 20 to 200 parts per million of each metal, and the content of these metals is of the same general magnitude in normal soil. The content of these metals is only slightly higher in soils from hillsides just above most of the fourteen veins studied. The soil directly over or immediately downhill from a vein commonly contains much higher concentrations of metal and may contain as much as 10,000 parts per million (1 percent). The ratios of the highest to the lowest metal value determined near each vein range up to 106 to 1 for copper, 170 to 1 for lead, and 11 to 1 for zinc. The range in metal content in the soils is high enough to permit easy detection of most of the geochemical anomalies by quick or "field-type" analytical methods.

The geochemical anomaly in soil near veins is broad and low in contrast to the sharp, high anomaly in the unweathered rock. The anomaly in soil is characteristically asymmetric, with normal or "background" values just uphill from the vein, an abrupt high near the vein, and progressively lower values extending as much as several hundred feet downhill. In general, the anomalies in soils have characteristics that can be explained by assuming a simple mechanical mixing of the vein and wall rock materials during weathering, and a downhill creep of the weathered products.

At some veins, chemical analysis of soils revealed the presence of sig-

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nificant quantities of ore metals for which no corresponding ore minerals were identified in the vein outcrop. Chemical analysis of soils also revealed the location of other veins even though they were completely hidden by residual soil. Two examples are described where chemical methods were used to locate concealed extensions of known veins. Prospecting by sampling surface soil at 50- to 100-foot intervals, and analyzing by quick tests apparently can locate some veins concealed by residual soil; however, there are many problems that must be solved before the limitations of this prospecting method can be defined adequately.

INTRODUCTION.

METALLIC ore deposits are commonly enveloped by a zone in which the ore metal concentration of the earth materials is lower than that of the ore, yet higher than that normally found in similar materials in areas distant from any ore. It is only recently, with the application of trace analysis to the study of ore deposits, that the full size of these transitional zones—geochemical "halos" or "anomalies"—has come to be appreciated. It has been shown that there are two kinds of anomalies: 1) "primary" anomalies in the unweathered country rock near the ore body and apparently syngenetic with the ore deposition; and 2) "secondary" anomalies in weathered rock, soil, alluvium, vegetation, or water near the ore, which are produced by weathering and other secondary processes acting upon the ore and country rock of the primary anomaly. Systematic search for geochemical anomalies has led to a discovery of a few new ore deposits and is receiving increasing attention as an aid in mineral exploration. The development of this technique of "geochemical prospecting" has been summarized by Sergeev (28),[2] Sokoloff (30), and Hawkes (12, 13).

For several years the U. S. Geological Survey has engaged in a program of developing and testing analytical methods suitable for geochemical prospecting, and conducting experimental geochemical investigations in the vicinity of known ore bodies. In brief, the program is designed to provide the mining industry with necessary information concerning the advantages and disadvantages of geochemical methods of prospecting. It is recognized that, if geochemical prospecting is to attain widespread usefulness, much basic information is needed concerning the size and nature of geochemical anomalies near known ore, how the anomalies can best be detected, and how they are related to the other geologic criteria commonly used in prospecting.

The present study was made to obtain preliminary information concerning geochemical prospecting by soil analysis. Suites of soil samples were obtained from the vicinity of fourteen metalliferous veins either partially or entirely concealed by residual soil. These samples were analyzed for copper, lead, and zinc using trace analytical methods. For comparison, similar analyses were made of soils derived from the weathering of common igneous rocks. In the text, the background geochemical data for normal rocks and soils is presented first. The next section presents the results of the chemical analyses of the soils collected near veins. Following sections interpret these results and give some conclusions regarding geochemical prospecting by soil analysis.

[2] Numbers in parentheses refer to Bibliography at end of paper.

It is believed that many of the conclusions reached may be applicable to geochemical prospecting for other kinds of metalliferous ore deposits.

ACKNOWLEDGMENTS.

The study of veins would have been impossible without the wholehearted cooperation of many geologists, both in the Geological Survey and in private mining companies, who suggested places for study and helped in sampling. Thanks in particular are due to H. E. Hawkes of the Geological Survey for constructive guidance of the investigation. The author is also particularly indebted to Hy Almond, Harold Bloom, Victor Kling, and J. P. Schuch, all of the Geological Survey, for the long hours required for analyzing the many samples.

METAL CONTENT OF NORMAL ROCKS AND SOILS.

To evaluate properly any abnormal content of metal in soils near ore deposits, it is necessary to consider the normal or "background" concentrations of metals in unmineralized rocks and related soils. Estimates of the copper, lead, and zinc content of normal rocks compiled recently by Rankama and Sahama (25, Table 5.52) are given in Table 1. In general, the content of these metals in rocks lies in the range of 20 to 200 parts per million, with zinc more abundant than copper and copper more abundant than lead.

Table 1 also gives estimates that have been made of the copper, lead, and zinc content of normal soils. The content of these metals in soil seems to be somewhat lower, commonly in the range of 10 to 100 parts per million. Again, zinc is more abundant than copper and copper is more abundant than lead. In making any interpretation based upon these values it should be remembered that trace analysis is difficult and that the results, in comparison with ordinary quantitative analysis, are relatively inaccurate. It should also be remembered that the sampling problem of selecting "average" material is extremely difficult, and may lead to an additional source of error. Nevertheless, it is apparent from the values given in Table 1 that the natural processes that trans-

TABLE 1.

AVERAGE COPPER, LEAD, AND ZINC CONTENT IN PPM OF NORMAL ROCKS AND SOILS. FIGURES IN PARENTHESES REFER TO BIBLIOGRAPHY.

	Material	Copper	Lead	Zinc
Rock (25)	Average igneous rock	70	16	132
	Sandstone	—	20	<20
	Shale	192	20	200–1,000
	Limestone	20.2	5–10	<50
Soil	Residual soil	20 (17, 23, 24)	12 (29)	71 (14)
		17 (9)	8 (18)	32 (1)
		28 (14)		
	Alluvial soil	20 (14)		94 (14)
Modern sediment	Silt	35 (24)		8 (4)

form rock into soil may involve a partial leaching and removal of the copper, lead, and zinc present in the parent rock, but that these metals are not totally removed.

The distribution of copper, lead, and zinc within the soil profile gives valuable clues to the behavior of these metals during soil formation. Soil scientists are in more or less general agreement that the copper and zinc content of soil is influenced by: 1) clay content, 2) organic content, and 3) acidity. Copper and zinc tend to accumulate in soils of high organic or clay content and tend to leach out of acid soils (10, 14, 33). In some soil profiles the copper and zinc are concentrated in the surface soil and in other profiles these metals are partially leached from the surface soil (14, 27). Lead may be enriched in the surface soil (29) or it may not be (2). Many of these studies of soil profiles show a definite correlation between the trace-metal content of the soil and that of the underlying material from which the soil was derived. These generalizations are based largely upon studies of agricultural soils, but the work described below suggests they also apply to mountain soils of the type commonly found in mining districts of the Front Range of Colorado.

To investigate the behavior of these metals in mountain soils, the writer sampled nine soil profiles developed on various igneous rocks in the northeastern part of the Front Range mineral belt. The igneous formations sampled include both intrusive and extrusive rocks of acid, intermediate, and basic composition. At each sample site, residual soil, weathered rock, and fresh rock were sampled separately.

In the Front Range near Denver the topographic and climatic conditions are more or less representative of many of the Rocky Mountain mining camps. The land slopes are steep and the soils are thin, stony lithosols with a vegetal cover of grass and pine trees. All soils were sampled on well-drained hillsides in such a way that, insofar as possible, the soil-forming factors were approximately the same except for parent material. From the youthful character of the soil it might be anticipated that a close relationship would be found between the chemical character of the soil and that of its parent material.

The soil samples represent the horizon within 12 inches of the land surface in which the rock and mineral particles are decomposed and thoroughly mixed by the weathering process. Most of the soils sampled are colored dark brown or black by intermixed organic material. The soil samples were sieved through a 2 mm-mesh iron sieve to remove roots and pebbles. The weathered rock samples represent the zone extending from a depth of about 1 to about 5 feet below the land surface; although the weathered rock is leached and chemically altered, it still retains its original texture. Most of the weathered rock crumbles easily and was sampled by channeling. The samples of fresh rock are a composite of chip samples taken between depths of 5 and 12 feet where there was no sign of weathering. To be certain of obtaining fresh rock, the sample sites were selected along roadcuts or other recent exposures.

Hy Almond, of the U. S. Geological Survey, analyzed the samples. The samples were ground to a fine powder and treated with a hydrofluoric-perchloric acid mixture in a platinum dish to decompose the silicates. The

samples were then heated to dryness and the residue dissolved in 1.0 *N* hydrochloric acid. The determination of copper, lead, and zinc was made by the method described by Holmes (15). The results are given in Table 2.

The average copper, lead, and zinc content of nine samples of fresh rock collected in the Colorado Front Range is 26, 31, and 79 parts per million, respectively, which contrasts with the 70, 16, and 132 parts per million given by Rankama and Sahama (25) as the average concentration of these metals in igneous rocks. Table 2 lists acid types of rocks first, intermediate types next, and basic types last, so that all rocks are listed roughly according to decreasing silica content. Although there are obscuring random deviations, both copper and zinc appear to be most abundant in the low silica rocks, but lead shows little or no relation to the silica content. Sandell and Goldich (26) also found more copper and zinc in basic igneous rocks, but found lead most abundant in acidic rocks. The intrusive stocks near Lyons, at Gold Hill,

TABLE 2.

COPPER, LEAD, AND ZINC CONTENT IN PPM OF RESIDUAL SOIL, WEATHERED ROCK, AND FRESH ROCK. ANALYSES BY HY ALMOND.

Type of rock	Description	Location of outcrop sampled in Colorado	Copper			Lead			Zinc		
			Fresh rock	Weathered rock	Soil	Fresh rock	Weathered rock	Soil	Fresh rock	Weathered rock	Soil
Rhyolite	Tuffaceous flow	West of Castle Rock	3	1	17	23	14	25	34	24	72
Granite	Silver Plume granite	Southwest of Lyons	13	19	17	32	35	18	54	50	80
Granite	Pikes Peak granite	Near Westcreek	8	10	11	29	25	29	94	46	180
Quartz monzonite	Boulder Creek granite	West of Boulder	38	9	29	40	20	65	48	54	76
Quartz monzonite	Intrusive stock	Southwest of Lyons	9	35	21	40	35	26	84	32	84
Monzonite porphyry	Intrusive stock	West of Gold Hill Station	10	9	11	41	41	47	58	100	90
Diorite	Intrusive stock	Jamestown	32	82	83	44	100	190	90	130	120
Basalt	Basalt at Table Mountain	East of Golden	65	58	45	14	8	33	140	110	120
Basalt porphyry	Ralston dike	North of Golden	57	42	56	20	16	21	110	110	130
		Average	26	29	32	31	33	50	79	72	110

and at Jamestown are believed to be related genetically to the ore deposits of the Colorado Front Range. Contrary to expectations, samples of these rocks do not have an unusually high base metal content.

In general, the metal content tends to be high in the soil if it is high in the fresh and weathered rock, and low in the soil if it is low in fresh and weathered rock. There is a slight tendency, shown best by the averages, for these metals to be enriched in the soil. These results obtained with mountain soils do not have much significance because of the limited number of samples studied. However, they do tend to confirm the hypothesis that these metals are not totally leached away during soil formation, and that soil sampling and analysis will give a rough indication of the metal content of the parent rock.

METAL CONTENT OF SOILS NEAR VEINS.

The foregoing estimates of the copper, lead, and zinc content of normal soils provide a basis for evaluating the copper, lead, and zinc content of soils found near ore bodies. From geologic literature, other pertinent information is available concerning the behavior of copper, lead, and zinc during the oxidation of sulfide ores above the water table. It is a common geologic observation, for example, that zinc tends to be leached from the zone of oxidation, whereas lead tends to be residually enriched. It is equally well established that copper is leached under certain conditions, as, for example, in environments where the weathering of associated iron sulfide produces acid ground waters, but is not leached where alkaline conditions prevail. From these observations it might be anticipated that much of the ore metal may have been leached away from the soils derived from the weathering of ore deposits. Any large-scale leaching of these metals from soils over ore deposits, combined with lack of leaching of these metals during the formation of normal soils, would, of course, constitute a situation unfavorable for prospecting by soil analysis.

Although the behavior of these metals in the soil overlying ore bodies may reflect the same general tendencies as in ore bodies, there is some direct evidence that not all of the ore metal is leached away. Sergeev (28), in summarizing the results of Russian experience in geochemical prospecting, indicates that copper, lead, and zinc are all found in unusual quantities in residual soils in the vicinity of ores of these metals. The same relation has been established for zinc at Friends Station, Tenn., by Hawkes and Lakin (11); for zinc at Austinville, Va., by Fulton (7); for copper near Røros, Norway, by Vogt and Bergh (34) and at San Manuel, Ariz., by Lovering et al. (22); for lead and zinc in the Coeur d'Alene district, Idaho, by Kennedy (19); for lead in the Tri-State district by Fowler (6); and for zinc and for total heavy metals in the Park City district, Utah, by Gilbert (8). It is evident that a substantial part of the metal content of the rock or ore, even including the relatively mobile metal, zinc, remains in the soil rather than being leached away.

It is difficult to compare the results of many of the studies made so far because of wide variations in the size and shape of the ore bodies, many of which are irregular and structurally complex. Difficulties of comparison are increased by the presence of primary haloes (primary anomalies) in the wall rock surrounding the ore. If the primary halo is large and comparisons are attempted on the basis of soil analysis, it may be difficult or even impossible to distinguish between the metal content in the soil derived from the ore and that derived from the rock of the primary halo.

Vein deposits were selected for this investigation to make the comparison between the ore deposits and their associated geochemical anomalies as simple as possible. On the assumption that veins have a relatively small primary halo, any abnormal metal content in the soil must be derived primarily from the ore itself. If soil samples are collected along a traverse extending directly downhill across veins, then the effects of dispersion of the ore metals by diffusion uphill can be compared with dispersion by diffusion, plus soil creep

and other gravitative effects on the downhill side. The writer has endeavored to collect samples of residual soil along traverses crossing veins of minable or nearly minable grade where the soil has not been disturbed or contaminated by mining activity.

Fourteen groups of samples were collected in what appeared to be likely places for obtaining well-defined geochemical anomalies. In the absence of better information, the grade of the ore in the veins sampled had to be judged from whether or not the vein had ever produced ore and, if it had produced ore, by the proximity of the sampled area to the productive mine workings. Three sample groups proved to be completely negative and their analyses are not given here; these sample groups were collected at 1) Copper King mine, Boulder County, Colo.; 2) White Raven mine, Boulder County, Colo.; and 3) an unnamed copper vein near Globe, Gila County, Ariz. There is no geologic evidence that any of these veins contain appreciable amounts of ore minerals where sampled—the lack of geochemical anomalies suggests that they are truly barren. Of the eleven sample groups in which chemical anomalies were found, four were collected at veins classified as commerical grade, four groups at veins of subcommercial grade, and three at veins that are weakly mineralized.

At each vein a pace and compass traverse was made, starting on the hillside above the vein and extending downhill so that the traverse crossed the vein at a high angle. Samples were collected at intervals along the traverse. Any surficial pebbles, plants, or vegetable litter was scraped from the land surface, and 100 or 200 grams of soil immediately beneath was collected and sieved through an aluminum-stainless steel sieve. The minus 2.0 mm fraction of the surface soil was retained in a manila envelope or cardboard carton and submitted for analysis. At two veins, samples were obtained of both surface soil and subsoil.

TABLE 3.

METAL CONTENT IN PPM OF SOIL SAMPLES COLLECTED NEAR AN UNNAMED VEIN, PORTER'S GROVE RANGE, IOWA COUNTY, WISCONSIN. ANALYSES BY HAROLD BLOOM, VICTOR KLING, AND J. P. SCHUCH.

Sample no.	Location of sample	Laboratory analysis[2]		Field analysis[3]				
		Zinc	Lead	General test[3a]	Zinc		Lead	
					[4]	[5]	[6]	[7]
1	Hillside above vein	400	110	400	300	300	50	200
2	50 ft. downhill	430	230	400	400	300	100	500
3	100 ft. downhill	420	270	400	400	300	100	500
4	150 ft. downhill	800	550	700	1,500	1,000	300	1,500
5	Over vein; 200 ft. downhill	2,600	4,400	3,000	2,000	2,000	800	8,000
6	250 ft. downhill	1,900	1,100	1,500	2,000	1,500	400	2,000
7	300 ft. downhill	1,500	690	1,500	2,000	1,500	300	1,500
8	350 ft. downhill	1,300	570	1,000	2,000	1,500	600	800
9	400 ft. downhill	1,100	460	800	1,000	1,000	200	400
10	450 ft. downhill	1,100	500	1,000	1,500	1,000	500	600

[2,3a,4,5,6,7] See Table 12 for brief description of analytical methods.

Veins Sampled.

Analyses of the soil samples are given in the accompanying tables. In each table the samples are listed consecutively, beginning with the one collected highest on the hillside above the vein and continuing in order along a traverse extending downhill across the vein.

Unnamed Vein, Porter's Grove Range, Iowa County, Wisconsin. (*Table 3, Fig. 1*).—This vein is located in the NE 1/4 sec. 21, T. 6 N, R. 4 E, near

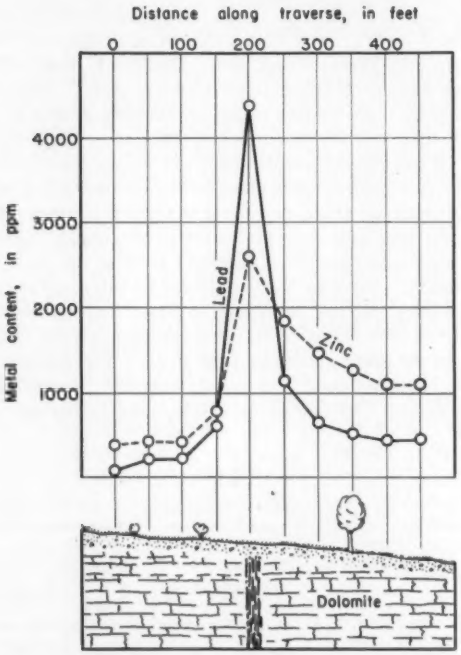

FIG. 1. Relationship between unnamed vein, Porter's Grove Range, Iowa County, Wis., and geochemical anomaly in residual soil.

Dodgeville, Wis. It is a fissure vein in dolomite, and contains lead and zinc sulfides. The soil samples were collected at 50-foot intervals along a traverse of gentle slope that crossed the vein at about right angles. The soil along the sample traverse is a dark-brown, humus-rich silt loam at the surface, and grades to a reddish-brown clay loam overlying weathered dolomite. The total depth of soil over the weathered dolomite probably averages two to three feet. A close comparison of the soil samples shows that the soil immediately over the vein is somewhat more reddish in color than normal soil elsewhere;

but at the time the samples were collected, no surface indication of the presence of the vein was noted. The position of the vein was determined by projection along the strike of the vein from exposures in prospecting pits several hundred feet distant. From past mining activity, it is assumed that the vein is subcommercial in the area sampled.

Iron King Vein, Yavapai County, Arizona (Table 4).—The Iron King mine is located in the SW 1/4 sec. 16, T. 13 N, R. 1 E, near Humbolt, Ariz. The deposit consists of several veins containing iron, lead, zinc, and some copper sulfides, with a little gold and silver. The samples were collected along a traverse following a low ridge crest in hilly terrain about 1,300 feet southwest of the working shaft. Along the sample traverse the country rock is hydrothermally altered schist containing some disseminated ore minerals immediately adjacent to the vein on both sides. The soil is very thin and rocky

TABLE 4.

METAL CONTENT IN PPM OF SOIL SAMPLES COLLECTED NEAR THE IRON KING VEIN, ABOUT ¼ MILE SOUTH OF THE SHAFT, IRON KING MINE, YAVAPAI COUNTY, ARIZONA. ANALYSES BY HAROLD BLOOM, VICTOR KLING, AND J. P. SCHUCH.

Sample no.	Location of sample	Laboratory analysis[1]			Field analysis			
		Copper	Lead	Zinc	General test[3b]	Copper[6]	Lead[7]	Zinc[4]
1	Ridge crest above vein	600	430	1,100	1,500	700	500	1,500
2	20 feet downhill	720	1,400	1,800	2,000	1,000	1,000	2,000
3	40 feet downhill	460	1,400	2,800	3,000	500	1,000	4,000
4	60 feet downhill	450	1,900	4,300	5,000	600	2,000	7,000
5	80 feet downhill; just below vein	700	Approx. 7,000	3,600	4,000	800	5,000	4,000
6	100 feet downhill	550	Approx. 7,000	5,500	10,000	600	5,000	4,000
7	120 feet downhill	560	Approx. 7,000	4,800	5,000	400	4,000	2,000
8	140 feet downhill	200	520	1,000	1,000	200	500	1,500
9	180 feet downhill	180	310	830	800	100	500	2,000
10	220 feet downhill	210	200	520	600	50	400	400

[1,3b,4,7,9] See Table 12 for brief description of analytical methods.

and, like most desert soils, lacks organic material. Rock outcrops are numerous in the area and the iron-stained, silicified vein is easily identified, although no ore minerals were observed in the vein outcrop. From past mining actively nearby, it is assumed that the vein where sampled is slightly less than ore grade and should be classified as subcommercial.

Collins East Vein, Mammoth St. Anthony mine, Pinal County, Arizona (Table 5 and Fig. 2).—The Mammoth St. Anthony mine is located in SW 1/4 sec. 26, T. 8 S, R. 16 E, at Tiger, Ariz. The vein sampled is a brecciated, silicified zone of commercial grade containing lead, molybdenum, vanadium, copper minerals, and some gold; the wall rock is rhyolite. The soil samples were collected along a traverse down the side of a very steep hill; the traverse crosses the vein about 100 feet east of the new Daugherty shaft.

The soil is rocky, iron-stained, of highly variable thickness, and intermixed with many large talus blocks. Rock outcrops are numerous, but the outcrop

TABLE 5.

METAL CONTENT IN PPM OF SOIL SAMPLES COLLECTED NEAR THE COLLINS EAST VEIN, MAMMOTH ST. ANTHONY MINE, PINAL COUNTY, ARIZONA. ANALYSES BY HAROLD BLOOM, VICTOR KLING, AND J. P. SCHUCH.

Sample no.	Location of sample	Laboratory analysis[1]	Field analysis	
		Lead	General test[1a]	Lead[1]
1	Hillside above vein	430	800	800
2	20 feet downhill	620	400	800
3	40 feet downhill	850	800	1,000
4	60 feet downhill, directly over vein	1,200	1,000	900
5	80 feet downhill	4,500	1,500	2,000
6	100 feet downhill	3,200	1,500	3,000
7	120 feet downhill	2,500	3,000	3,000
8	140 feet downhill	3,400	3,000	1,000
9	160 feet downhill	2,300	1,500	1,500
10	180 feet downhill	2,000	1,000	1,500

[1,1a,1] See Table 12 for brief description of analytical methods.

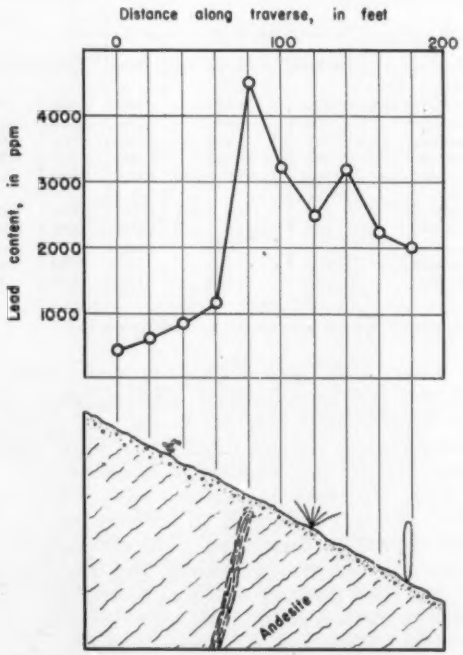

FIG. 2. Relationship between Collins East vein, Mammoth St. Anthony mine, Pinal County, Ariz., and geochemical anomaly in residual soil.

of the vein cannot be identified from the undisturbed surface; when the samples were taken the Mammoth St. Anthony Mining Company was in the process of tracing the vein by digging test pits. The vein is identifiable in the test pits as an iron gossan containing fragments of wulfenite.

Unnamed Copper Vein, Pima County, Arizona (*Table 6*).—This vein is located in the SW 1/4 sec. 35, T. 16 S, R. 12 E, at Mineral Hill, about 15 miles southwest of Tucson, Ariz. It is located near the top of Mineral Hill and is a simple fissure filling, about 1 foot wide, in limestone. The soil is very thin and rocky; the vein is well exposed and easily recognized as copper-bearing by the greenish stain of copper carbonate. The vein is much too small to be of economic importance; it is classified as mineralized.

TABLE 6.

METAL CONTENT IN PPM OF SOIL SAMPLES COLLECTED NEAR A SMALL, UNNAMED COPPER VEIN, PIMA COUNTY, ARIZONA. ANALYSES BY HAROLD BLOOM, VICTOR KLING, AND J. P. SCHUCH.

Sample no.	Location of sample	Laboratory analysis[2]	Field analysis		
		Copper	General test[2a]	Copper[3]	Copper[3]
1	Top of hill	170	200	200	300
2	10 feet downhill	300	150	300	500
3	20 feet downhill, just below small copper vein	710	500	500	500
4	30 feet downhill	930	900	900	1,500
5	40 feet downhill	750	600	900	1,000
6	50 feet downhill	690	600	800	700
7	60 feet downhill	460	800	400	600
8	70 feet downhill	410	700	300	400
9	90 feet downhill	340	600	400	500
10	110 feet downhill	440	500	600	400

[2,2a,3,9] See Table 12 for brief description of analytical methods.

Apache Vein, Gila County, Arizona (*Table 7*).—This vein was sampled in the NW 1/4 sec. 2, T. 1 N, R. 15 E, about 600 feet south of the Apache (vanadium) mine shaft, and about 5 miles north of Globe, Ariz. It was mined for its lead and vanadium content at the shaft but no ore minerals were identified where the vein was sampled. Where sampled, the vein is a quartz body several feet wide in shale and is easily traced. The samples were collected along the crest of a low ridge. The soil is thin and contains some fragments of quartz float from the vein. The vein is much too lean where sampled to be of commercial importance; it is classified as mineralized.

Pittsburg Vein, Coeur d'Alene district, Shoshone County, Idaho (*Table 8*).—The Pittsburg vein is located about 4 miles south of Smelterville at the Pittsburg mine (also called Little Pittsburg mine), in the NW 1/4 sec. 27, T. 48 N, R. 2 E. The vein is a fissure filling of lead, zinc, and iron sulfides in fine-grained quartzite. The topography is mountainous, and the soil is a pebbly dark-brown loam several feet deep.

TABLE 7.

METAL CONTENT IN PPM OF SOIL SAMPLES COLLECTED NEAR THE APACHE VEIN, GILA COUNTY, ARIZONA. ANALYSES BY HAROLD BLOOM, VICTOR KLING, AND J. P. SCHUCH.

Sample no.	Location of sample	Laboratory analysis[1]	Field analysis
		Lead	General test[2a]
1	Hillside above vein	40	100
2	20 feet downhill	15	50
3	40 feet downhill	30	50
4	60 feet downhill	60	100
5	80 feet downhill, on vein	110	300
6	100 feet downhill	220	700
7	120 feet downhill	120	200
8	140 feet downhill	20	100
9	160 feet downhill	20	150
10	180 feet downhill	40	150

[1,2a] See Table 12 for brief description of analytical methods.

TABLE 8.

METAL CONTENT IN PPM OF SAMPLES COLLECTED NEAR THE PITTSBURG VEIN, COEUR D'ALENE DISTRICT, SHOSHONE COUNTY, IDAHO. ANALYSES BY HAROLD BLOOM, VICTOR KLING, AND J. P. SCHUCH.

Sample no.	Location of sample	Laboratory analysis[2]			Field analysis					
		Lead	Zinc	Copper	General test[2a]	Lead		Zinc		Copper[8]
						8	7	5	4	
1	Hillside above vein, upper traverse	280	280	—	400	100	100	200	70	—
2	50 feet downhill	100	240	—	200	0	100	100	300	—
3	100 feet downhill	80	200	—	200	40	200	100	200	—
4	150 feet downhill	90	240	—	100	20	200	70	200	—
5	200 feet downhill	100	270	—	200	0	300	100	300	—
6	250 feet downhill, over vein (?)	12,000	580	100	4,000	1,000	20,000	300	300	60
7	300 feet downhill	4,300	530	—	800	5,000	8,000	300	100	—
8	350 feet downhill	410	210	—	400	300	400	100	150	—
9	450 feet downhill, end of upper traverse	70	220	—	300	70	100	100	300	—
10	Hillside above vein, lower traverse	130	230	—	200	0	300	200	300	—
11	50 feet downhill	140	250	—	150	0	700	300	300	—
12	100 feet downhill, over vein	3,900	840	50	1,500	1,000	2,000	700	500	—
13	150 feet downhill	8,000	1,500	80	5,000	1,500	4,000	1,000	1,000	80
14	200 feet downhill	5,200	1,600	—	3,000	1,500	8,000	1,000	1,000	—
15	300 feet downhill	3,500	1,800	—	3,000	1,000	3,000	2,000	2,000	—
16	400 feet downhill	2,800	1,500	—	1,500	800	3,000	1,000	900	—
17	490 feet downhill, end of lower traverse	13,000	2,200	70	7,000	6,000	30,000	1,000	200	100

[2,2a,4,5,6,7,8] See Table 12 for brief description of analytical methods.

Samples were collected along two traverses across the vein. The upper sample traverse was established about 1,600 feet north of the mine adit along a ridge crest, where there is no surface indication of the presence of the vein. A company geologist familiar with the mine estimated that the vein passed close to sample locality 4; the analytical results, however, indicate that it is located about 100 feet farther downhill. The lower sample traverse was established about 1,000 feet northeast of the adit, down a steep hillside. The location of the vein on this traverse was determined by a mine stope that had caved to the land surface; other than the stope there were no surface indications of the ore. The samples were collected to one side of the stope so that there is little chance of contamination by the workings. The vein is probably of ore grade where crossed by both traverses; it is classified as commercial. The high value at the lower end of the lower traverse led to the discovery of a new vein nearby.

Chicago Vein, Blackbird District, Lemhi County, Idaho (Table 9).—The Chicago vein is located in the hillside east of Meadow Creek, in the headwaters of Blackbird Creek near the new town of Cobalt, Idaho, where the topography is rugged and mountainous. The vein was sampled in and near an exploratory bulldozer cut made by the Bureau of Mines about 500 feet southeast of the Brown Bear shaft, and at the base of a steep hillside. Where sampled the vein is a copper- and cobalt-bearing shear zone in fine-grained quartzite; it is of commercial grade. The soil consists of several feet of rocky dark-brown loam intermixed with many talus blocks. Although much iron-stained vein quartz can be found on the hillside, the vein exposures are poor and the vein sampled is difficult to trace. Data for both cobalt and copper are given in Table 9; this group of samples is the only group analyzed for cobalt.

TABLE 9.

METAL CONTENT IN PPM OF SOIL SAMPLES COLLECTED NEAR THE CHICAGO VEIN, BLACKBIRD DISTRICT, LEMHI COUNTY, IDAHO. ANALYSES BY HAROLD BLOOM, VICTOR KLING, AND J. P. SCHUCH.

Sample no.	Location of sample	Depth below land surface in feet	Laboratory analysis		Field analysis		
			Copper[2]	Cobalt[10]	General test[9a]	Copper[9]	Cobalt[11]
1	Hillside above vein	0	100	56	100	100	80
2	Do.	2	220	100	300	200	150
3	100 feet downhill	0	90	70	100	300	80
4	Do.	2	440	200	300	700	150
5	200 feet downhill in bulldozer cut on vein	0	160	100	150	—	100
6	Do.	2	950	390	800	700	300
7	Do.	4	3,000	320	2,000	2,000+	100
8	Do.	8	1,500	200	800	1,000	150
9	Do.	12	1,700	1,100	700	2,000+	600
10	Do.	16	1,500	650	2,000	600	400
11	300 feet downhill	0	150	85	150	400	100
12	Do.	1	720	180	600	1,000	200
13	Do.	3	1,600	400	1,000	2,000+	400
14	400 feet downhill	0	400	80	150	300	150
15	Do.	1	1,100	180	1,000	1,000	300
16	Do.	2½	1,100	240	800	1,000	300

[2,9a,9,10,11] See Table 12 for brief description of analytical methods.

Malachite Vein, Jefferson County, Colorado (Tables 10a, 10b, and 10c, and Fig. 3).—The Malachite vein is located at the Malachite mine, in the N 1/2 sec. 30, T. 4 S, R. 70 W, about 2 miles northwest of the small town of Idledale, Colo. The vein is a mineralized shear zone in gneiss and schist that contains iron and copper sulfides and minor amounts of zinc. Samples were collected along two parallel traverses that extend down a steep hillside. The west traverse crosses the vein about 500 feet northeast of the portal of the west

TABLE 10a.

METAL CONTENT IN PPM OF SAMPLES OF SURFACE SOIL COLLECTED ALONG WEST TRAVERSE ACROSS MALACHITE VEIN, JEFFERSON COUNTY, COLORADO. ANALYSES BY HAROLD BLOOM, VICTOR KLING, AND J. P. SCHUCH.

Sample no.	Location of sample	Laboratory analysis[2]			Field analysis		
		Copper	Zinc	Lead	General test[3a]	Copper[3]	Zinc[4]
1	Hillside above vein	50	80	25	50	50	120
2	50 ft. downhill	50	120	45	80	10	80
3	100 ft. downhill	100	85	20	100	10	80
4	150 ft. downhill	340	160	10	200	300	150
5	200 ft. downhill, over vein	5,300	500	60	2,000	4,000	800
6	250 ft. downhill	1,900	410	40	800	1,000	400
7	300 ft. downhill	830	260	55	400	500	400
8	350 ft. downhill	510	270	40	300	400	300
9	400 ft. downhill	440	210	30	200	200	300
10	450 ft. downhill	300	160	35	100	300	200
11	550 ft. downhill	350	260	35	300	300	300
12	650 ft. downhill	400	210	70	500	300	300

[2, 3a, 4, 5] See Table 12 for brief description of analytical methods.

TABLE 10b.

COPPER CONTENT IN PPM OF SOIL SAMPLES COLLECTED AT VARIOUS DEPTHS ALONG WEST TRAVERSE ACROSS MALACHITE VEIN, JEFFERSON COUNTY, COLORADO. ANALYSES BY HAROLD BLOOM.

Surface sample no.	Location of sample	Copper content[2] of samples at various depths (in feet) below land surface				
		0.0 ft.	0.5 ft.	1.0 ft.	1.5 ft.	2.0 ft.
1	Hillside above vein	50	85	60	160*	
2	50 ft. downhill	50	65	90*		
3	100 ft. downhill	100	50	60	50*	
4	150 ft. downhill	340	1,600	1,000	1,800	1,400*
5	200 ft. downhill, over vein	5,300	2,900	6,500	15,000*	
6	250 ft. downhill	1,900	1,200	950*		
7	300 ft. downhill	830	500	180*		
8	350 ft. downhill	510	410	260*		
9	400 ft. downhill	440	300	310	250*	
10	450 ft. downhill	300	280	280	150*	
11	550 ft. downhill	350	300	290	300*	
12	650 ft. downhill	400	280	350	180*	

* Weathered rock.

[2] See Table 12 for brief description of analytical method.

TABLE 10c.

METAL CONTENT IN PPM OF SOIL SAMPLES COLLECTED ALONG EAST TRAVERSE ACROSS MALACHITE VEIN, JEFFERSON COUNTY, COLORADO. ANALYSES BY HAROLD BLOOM, VICTOR KLING, AND J. P. SCHUCH

Sample no.	Location of sample	Laboratory analysis, copper[2]	Field analysis		
			General test[2a]	Copper[3]	Zinc[4]
1	Hillside above vein	50	80	10	90
2	50 ft. downhill	55	80	20	60
3	100 ft. downhill	60	50	10	60
4	150 ft. downhill	70	100	50	90
5	200 ft. downhill	400	300	500	200
6	250 ft. downhill	240	300	150	200
7	300 ft. downhill	160	200	100	200
8	350 ft. downhill	100	100	80	100
9	400 ft. downhill	80	100	10	100
10	450 ft. downhill	85	80	50	—

[2,2a,4,3] See Table 12 for brief description of analytical methods.

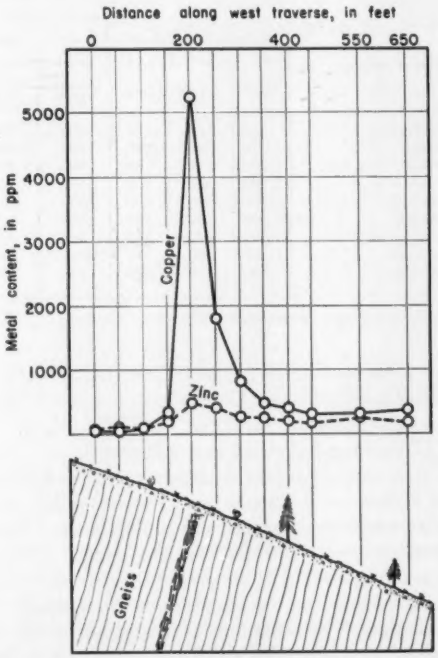

FIG. 3. Relationship between Malachite vein, Jefferson County, Colo., and geochemical anomaly in residual soil.

tunnel; the east traverse crosses an extension of the vein about 200 feet northeast of the portal of the east tunnel.

The soil is a brownish-black loam intermixed with many talus blocks. Along the west traverse the vein does not crop out, but its location can easily be determined from gossan float derived from the vein, some fragments of which are coated with malachite. The vein here is probably slightly less than ore grade and is classified as subcommercial. On this traverse, samples were taken of the surface soil and of deeper soil horizons at 6-inch depth intervals until the bottom sample was collected in weathered bed rock. Along the east traverse there is no iron-stained float or other visible evidence to indicate the location of the vein; its position was estimated by extrapolation from its known position to the west. The vein where crossed by the east traverse must be much less than ore grade and is classified as mineralized.

TABLE 11.

METAL CONTENT IN PPM OF SOIL SAMPLES COLLECTED NEAR THE UNION COPPER VEIN, GOLD HILL DISTRICT, CABARRUS COUNTY, NORTH CAROLINA. ANALYSES BY HAROLD BLOOM, VICTOR KLING, AND J. P. SCHUCH.

Sample no.	Location of sample	Laboratory analysis[2]			Field analysis			
		Lead	Copper	Zinc	General test[3a]	General test[3b]	Lead[7]	Copper[8]
1	Hillside above vein	150	160	220	200	200	15	100
2	40 ft. downhill	220	200	280	200	300	50	200
3	80 ft. downhill, over vein	2,200	720	460	600	700	700	600
4	110 ft. downhill	2,500	430	430	500	700	600	400
5	145 ft. downhill	1,200	340	680	600	500	700	1,000
6	180 ft. downhill	1,700	230	520	500	600	300	200
7	205 ft. downhill	1,600	290	310	300	300	400	150
8	230 ft. downhill	1,400	290	310	300	200	200	200
9	255 ft. downhill	800	150	230	200	300	70	80

[2,3a,3b,7,8] See Table 12 for brief description of analytical methods.

Union Copper Vein, Gold Hill District, Cabarrus County, North Carolina (*Table 11 and Fig. 4*).—The Union Copper vein is at the Union Copper Mine, about 1.5 miles southwest of the village of Gold Hill, N. C. Gold Hill is on U. S. Highway 52 between Salisbury and Albemarle.

The vein is in a zone of minor faulting in highly altered quartzite and schist. The ore bodies are lenticular and consist mainly of zinc and iron sulfides, with lesser amounts of copper and lead sulfides. The outcrop of the ore body is marked locally by a prominent iron gossan. The sample traverse was taken along a very gentle hillslope across the ore body, where there is no gossan but where a reddish-iron discoloration of the normally dark-brown clay soil reveals the location of the vein. Where crossed by the sample traverse, the vein is probably somewhat less than ore grade and is classified as subcommercial.

Analytical Methods.

The soil samples collected near veins were analyzed both by a standard laboratory method and by various field methods or quick tests in which accuracy has been sacrificed for speed. The analytical methods used for the analysis of the soil samples collected near veins are described very briefly in Table 12; most of them are described in greater detail in the compilation of field tests used in geochemical prospecting by the U. S. Geological Survey (20). All of the analyses were made by Survey chemists Harold Bloom,

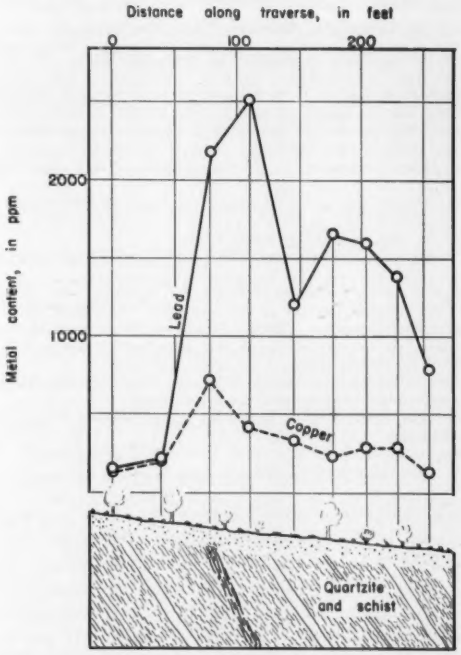

FIG. 4. Relationship between Union Copper vein, Gold Hill district, Cabarrus County, N. Car., and geochemical anomaly in residual soil.

J. P. Schuch, and Victor Kling in the Denver laboratory of the Geological Survey. The analyses were made in such a manner that the analysts had no record of previous analytical results and did not know the position of the sample point in relation to the ore body.

The laboratory method used is an accepted procedure for the determination of copper, lead, and zinc in soil. The laboratory method utilizes an accurate photoelectric colorimeter for the final estimation of the amount of metal present; the errors in the laboratory method probably average no more than 10

percent. In general, the results given by laboratory analysis of the sample groups show a smooth, even fluctuation of the metal content along the length of the traverse. The change is so regular from sample to sample in some of the groups that it appears probable that additional samples, collected at intermediate locations, would have a metal content intermediate between those of the two adjacent samples. The gradational character of the metal content is a reassurance that sampling errors and analytical errors are small in comparison with the size of the anomalies.

TABLE 12.

BRIEF DESCRIPTION OF ANALYTICAL METHODS USED FOR OBTAINING THE DATA PRESENTED IN TABLES 3 TO 11. FOOTNOTE NUMBERS IN THOSE TABLES CORRESPOND TO ITEM NUMBERS 2 TO 11 LISTED BELOW.

2. Laboratory methods devised by R. S. Holmes, U. S. Department of Agriculture (15).
3a. General field test for ore metals as zinc, copper, or lead in soil (16). Samples digested in aqua regia. The results are expressed in zinc equivalents and, for comparison with the laboratory analysis, the laboratory analysis should be expressed as zinc plus 1/2 copper plus 1/4 lead because of the differing behavior of each metal with the determinant, dithizone.
3b. Similar to item No. 3a, but with preliminary treatment in hydrofluoric acid to decompose silicates.
4. Field test for zinc, using a $KHSO_4$ fusion (21).
5. Field test for zinc, using concentrated HNO_3 for digestion, but otherwise similar to item No. 4.
6. Field test for lead, using concentrated HNO_3 for digestion, and dithizone for the determination. Determination is made as the mono-color dithizonate under alkaline conditions and in the presence of cyanide. Method devised by Hy Almond, U. S. Geol. Survey (20).
7. Field test for lead, similar to item No. 6, but using solid NH_4F and H_2SO_4 as digestants. Method devised by Harold Bloom, U. S. Geol. Survey.
8. Field test for copper, using concentrated HNO_3 for digestion, and determining as a mixed-color dithizonate under slightly acid conditions (22).
9. Field test for copper, using $KHSO_4$ fusion for the digestion and rubeanic acid filter paper in the "chromograph" (32).
10. Laboratory test for cobalt (5).
11. Field test for cobalt, using $KHSO_4$ fusion for the digestion (3).

The field-type analytical methods commonly use a less rigorous digestion method than is used in the laboratory method; therefore, there commonly is an error in the field analyses caused by incomplete extraction of the heavy metal from the sample. In addition, a large non-systematic error is introduced in the field-type analysis by relying upon the visual comparison of colors for the final estimation of the amount of metal present. If the analytical results obtained by laboratory and field methods are compared in Tables 3 to 11, it can be seen that the concentrations as determined by field methods are commonly the smaller, and give a poorer definition of smooth, natural variations than concentrations determined by the laboratory method. Under good conditions, the average error of the field-type analysis is probably about 20 to 30 percent.

One of the major problems in geochemical studies is the selection of the best analytical method for a given field problem. Chemical methods vary in refinement. As more and more refinements are included in the procedure the determination becomes both more accurate and more time consuming. It is apparent that there are two dangerous extremes that must be avoided: one

is to simplify the procedure to a point where significant differences are missed completely; the other is to include refinements in the procedure to the point where the cost is too high to permit analysis of an adequate number of samples. Thus, depending on the nature of the individual problem, a happy medium must be found between these two extremes.

The experience of the Geological Survey chemists in making analyses for copper, lead, and zinc in soil indicates that about 6 laboratory determinations or about 50 of the field-type determinations can be made by a chemist in one day. It is the writer's experience that, on the average, about 50 surface soil samples can be collected by one man in a day. Although the field-type analyses are not as accurate as laboratory analyses, many of the vein-indicating anomalies in soil are so strong that field-type analyses seem entirely adequate for their detection and definition. Under these conditions, it seems apparent that the manpower requirements for analyzing samples should not exceed those for collecting samples in a large-scale geochemical prospecting program.

INTERPRETATION OF DATA.

Magnitude of the Geochemical Anomalies.

The analytical data show that abnormal amounts of copper, lead, and zinc are commonly found in residual soil in the vicinity of veins containing these metals. In addition, the data in Tables 3 to 11 show that the metal content of soils collected near veins varies widely within comparatively short distances. This range of copper, lead, and zinc concentrations in each of the soil sample groups is summarized in Table 13. If the difference between the highest and lowest metal content is expressed as a ratio, the observed ratios are as much as 106 to 1 for copper, 170 to 1 for lead, and 11 to 1 for zinc.

The low or "background" values found near veins, as given in Table 13, appear to be somewhat higher than the "normal" metal content for soil, as given in Table 1. Table 13 also shows that the highest metal content of soils found near veins falls far short of commercial grade ore. To complete the picture, it would be highly desirable to have data for the metal content of unweathered rock and ore along the same traverses covered by soil sampling Although the lack of such data prevents quantitative comparison, it seems evident that if the lowest metal content of soil samples near veins is higher than that of "average rock" and if the highest metal content of soil samples is lower than that of ore, the total range in metal content in soil near veins cannot be nearly as large as the range in metal content in the corresponding parent rock and vein material.

It is evident from the analytical results that the abnormally high concentrations of metal in the soil are distributed over a larger area than the corresponding high concentrations in the bed rock. In several of the sample traverses, such as that from the Chicago vein, the lower traverse across the Pittsburg vein, and the west traverse across the Malachite vein, the soil anomaly is detectable several hundred feet from the vein, whereas the veins themselves average about 10 feet in width.

TABLE 13.

RANGE OF COPPER, LEAD, AND ZINC CONTENT (IN PPM) OF SOILS COLLECTED NEAR VEINS. VEINS ARE CLASSIFIED AS COMMERCIAL (C), SUBCOMMERCIAL (SC), AND MINERALIZED (M) IN THE ORDER OF DECREASING GRADE.

Vein	Classification	Copper			Lead			Zinc		
		High	Low	Ratio	High	Low	Ratio	High	Low	Ratio
Unnamed vein, Porter's Grove Range, Iowa County, Wis.	SC				4,400	110	44	2,600	400	6
Iron King vein, Yavapai County, Ariz.	SC	720	180	4	7,000	200	35	5,500	520	11
Collins East vein, Mammoth St. Anthony mine, Pinal County, Ariz.	C				4,500	430	10			
Unnamed copper vein, Pima County, Ariz.	M	930	170	5						
Apache vein, Gila County, Ariz.	M				220	15	14			
Pittsburg vein, Coeur d'Alene district, Shoshone County, Idaho — upper traverse	C				12,000	70	170	580	200	3
Pittsburg vein, Coeur d'Alene district, Shoshone County, Idaho — lower traverse	C				13,000	130	100	1,800	230	8
Chicago vein, Blackbird district, Lemhi County, Idaho	C	1,600	220	7						
Malachite vein, Jefferson County, Colo. — west traverse	SC	5,300	50	106				500	80	5
Malachite vein, Jefferson County, Colo. — east traverse	M	400	50	8						
Union Copper vein, Gold Hill district, Cabarrus County, N. C.	SC	720	150	5	2,500	150	17	680	220	3

The contrast between the broad, low anomalies observed in the soil and the sharp, high anomalies in bed rock can be explained, at least in part, by the mixing action of the soil-forming process. During weathering the soil derived from the ore is always mixed with some of the soil derived from adjacent wall rock. Therefore, the maximum metal content of the soil must always be less than that of the ore. Similarly, a little of the vein material is always incorporated in the soil derived from wall rock near the vein; therefore, the area of anomalously high metal content in the soil is always broader than the vein itself.

Relation of Geochemical Anomaly to Vein.

The geochemical anomaly developed in the soil appears to have a definite relation to the position of the vein. As can be seen in Figures 1 to 4, soils uphill from the vein have a low metal content, corresponding to the background in the area. As the traverse is followed downhill across the vein, the metal content in the soil increases abruptly close to the vein. Soil samples taken progressively farther downhill along the traverse show a gradual decline in metal content.

At the Malachite vein, samples were collected of surface soil and of deeper soil horizons down to and including weathered rock, in order to obtain some information concerning the vertical distribution of the soil anomaly. The copper content of these samples is given in Table 10b. Figure 5, a modification of a figure given by Sergeev (28, Fig. 6) illustrates a chemical anomaly produced by mechanical dispersion and downhill creep in soil over a vein paralleling the topographic contours. Sergeev's concept agrees well with the data obtained in this investigation. This concept and the observed relations suggest the following generalizations: 1) the area of highest metal content in

the surface soil is located on the hillside at or just downhill from the vein; 2) the anomaly in the surface soil is asymmetric, with its peak close to the vein and with a long tail extending downhill; and 3) the anomaly is largest areally in the surface soils but strongest in deeper soil horizons.

Cause of Geochemical Anomalies.

It seems probable that the nature of the soil anomaly can be affected by many different factors besides the amount of ore metal in the veins. For example, the ore metal causing the geochemical anomaly may have been

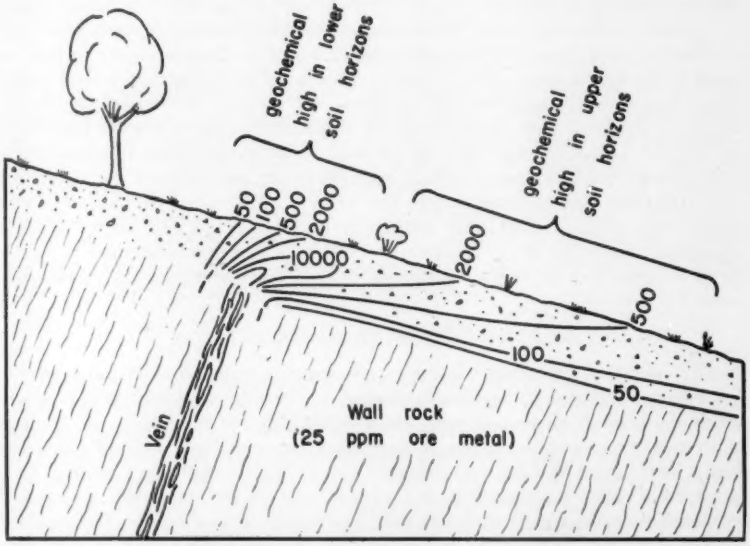

FIG. 5. Cross section of hypothetical copper, lead, or zinc vein and its geochemical anomaly produced by mechanical dispersion in residual soil. Concentration boundaries of vein metal given in ppm. Modified from Sergeev (28, Fig. 6).

derived in part from the vein itself and in part from mineralized wall rock bordering the vein. If most of the ore metal is concentrated in the vein, the soil anomaly probably will tend to be high and sharp, whereas if much of the ore metal is in the wall rock, the soil anomaly probably will be more broad and rounded. In addition, the nature of the anomaly must reflect the behavior of the ore metal during weathering. It is conceivable that a certain amount of dispersion, whether by solution or mechanical means, can take place uphill against the pull of gravity. Dispersion might also be gravity-controlled. If it takes place by solution, the metal will be carried downward in percolating ground water and the outcrop of the ore body will be leached. If the metal is insoluble, however, it will remain in the soil and will be dispersed mechanically

downhill as the soil creeps down the land surface. Sergeev (28) gives a theoretical discussion of various forms taken by anomalies.

The existence of a large primary anomaly and diffusion uphill, as well as down, are factors favoring a symmetrical anomaly in the soil on both sides of the vein, regardless of landslope. Conversely, gravity-controlled, mechanical dispersion should favor formation of a large, asymmetric anomaly with a long extension in the downhill direction. Because most of the observed soil anomalies near veins are of the asymmetric type, it seems logical to conclude that primary anomalies near veins are small and that gravity-controlled, mechanical dispersion is the major factor in the formation of the secondary or soil anomalies.

There is a little evidence of leaching of the ore metals from the surface soil. At the Union Copper vein the proportion of zinc to lead is higher in the ore than in the soil, a suggestion of partial removal of the relatively mobile metal, zinc, during soil formation. In addition, surface soil at the Blackbird vein seems to be somewhat depleted in ore metal in comparison with lower soil horizons. However, the effect of leaching of ore metals from soil near veins seems to be small in comparison to leaching of ore metals from the supergene zone of many disseminated sulfide ore bodies. The nature of the anomalies near veins suggests that after incorporation in the soil the ore metals are practically insoluble in soil moisture. In spite of any leaching, the ore metals tend to remain in abnormal and easily detectable amounts in the surface soil near veins.

Effect of Topography.

The shape of the geochemical anomaly appears to be modified considerably by the local topography and, in particular, by the diluting effect of barren soil from the hillside above the vein. If a vein crops out high on a hillside and close to the topographic divide, it apparently has a shallow residual soil cover and yields a strong chemical anomaly. Low on the hillside a similar vein apparently yields a weak anomaly, probably because the soil cover is deep and comes from a large area so that the anomaly is greatly diluted. The samples collected across the Chicago vein were collected near the foot of a high hill; the anomaly is relatively weak at the vein, even though the vein is of commercial grade. In contrast, the wet traverse across the Malachite vein, of subcommercial grade, is high on the hillside and revealed a very strong anomaly at the vein.

The geochemical anomaly on ridges tends to be very strong and the "tail" of the anomaly short. The thin soil on a ridge crest probably represents minimum dilution because soils formed on ridge crests are derived locally, and tend to creep downhill on either one side or the other of the ridge. Examples of this type of anomaly are the traverse across the Iron King vein and the upper traverse across the Pittsburg vein. In every example studied, the nature of the anomaly appears to be consistent with the manner in which the topography controls soil creep.

Many common topographic situations were not investigated. For example, no samples were collected of the relatively deep soils found in topog-

raphic depressions. It probably can be anticipated that in any topographic depression the deep soils represent much material contributed from the surrounding hillside and any anomaly in the depression will be correspondingly weakened. Other common situations not investigated are those in which the vein extends up and down the landslope, and where samples are collected as a traverse along the topographic contour and crossing the vein at a high angle. Sergeev (28, Fig. 7) gives an example of this kind of anomaly, which is highest over the vein and is symmetrical on both sides of the vein. Of course, many other possible topographic situations could be investigated; it seems likely that in these other situations residual soil anomalies will be found to have a shape consistent with the manner in which the topography controls soil creep.

Effect of Non-residual Soils.

Surface soils that are not of residual origin may not exhibit a geochemical anomaly related to an underlying ore deposit. Sergeev (28, Fig. 12B) described one anomaly completely covered by a thick layer of colluvium; similar instances have been observed by Sokoloff (31) in Australia, where an anomaly is covered by caliche and alluvium; and by V. C. Kennedy (personal communication) in southwestern Wisconsin, where residual soil exhibiting an anomaly is covered by barren loess. It seems likely that in areas covered by till or other glacial deposits any geochemical anomalies will be radically different from those developed in residual soil.

APPLICATION OF RESULTS TO PROSPECTING.

Geochemical methods are of little practical value if they merely confirm what can be learned by the customary geologic methods of prospecting. Copper-bearing veins are especially easy to identify visually because oxidized copper minerals such as malachite and chrysocolla are easily recognized. The unnamed copper vein, Pima County, Ariz., and the Malachite vein (west traverse) are easily identified as copper-bearing because of the presence of malachite and chrysocolla. The oxidized minerals of zinc and lead are not as easily identified as those of copper. The Iron King vein has an obvious silicified outcrop but no recognizable ore minerals, even though the soil samples from this vein contain as much as 700 ppm copper, 7,000 ppm lead, and 5,000 ppm zinc. How different is the situation at the Apache vein, which also has an obvious outcrop, also contains no recognizable ore minerals, yet yielded a geochemical anomaly of only 200 ppm lead! This contrast and others that can be drawn from other veins suggest that soil analysis techniques may be a useful supplement to geologic examination for the appraisal of prospects.

Some of the veins studied were completely concealed by the residual soil. Veins that are completely concealed, yet have a large and easily detectable geochemical anomaly, include the unnamed vein, Iowa County, Wis., the Collins East vein, the Pittsburg vein (upper traverse), the Malachite vein (east traverse), and the Chicago vein. These veins had been located by prospecting pits, bulldozing trenches, or by underground mining.

In the upper soil sample group collected across the Pittsburg vein there were no prospect pits or other workings to help in the exact location of the vein. The mining geologist who had mapped the local geology estimated that the soil traverse would cross the vein at or near sample site 4. Actually, the abrupt increase in metal content occurs at sample 6, which is interpreted as indicating the approximate location of the vein, although no digging was attempted to check the interpretation. Sample 6 contains 12,000 ppm lead, over 1 percent, yet there is no visible evidence of the presence of the vein. Sample 17 of the lower traverse across the Pittsburg vein has a high lead content which could not be interpreted in terms of any known veins. Current studies being made by Kennedy (19) have confirmed the presence of a strong anomaly at sample site 17 and discovered a vein previously unknown to the mine operators.

The east traverse across the Malachite vein was made to determine whether chemical methods could be used to locate the extension of the vein beyond the principal ore bodies in an area where there are no surface indications of mineralization. Sample analyses located the vein in the vicinity of sample site 5. This sample contains 400 ppm copper, yet there is no visible evidence of this copper content.

It seems evident from these examples that chemical methods can be used under favorable conditions for locating extensions of known ore deposits. It seems quite likely that systematic studies of favorable areas by the same methods could be used as a prospecting method to locate additional ore deposits. To date, published descriptions of successful applications of soil analysis to the discovery of ore deposits are confined to examples given by Sergeev (28) and by Fowler (6). In view of the small number of geochemical prospecting investigations that have been made, these discoveries should probably be regarded as promising a profitable future for the methods.

The nature of the geochemical anomaly near veins permits some suggestions to be made regarding the collection of samples. Surface soils of residual origin show maximum dispersion of the anomaly; therefore, if the objective is to cover large areas rapidly, it seems advisable to collect soil from the land surface at intervals of, say, 50 or 100 feet. Detailed locations can be made by sampling deeper soil horizons or weathered rock at closer intervals. It can be noted, by examining Figure 5, that the sampling of the deeper soil horizons or the weathered rock at wide intervals may completely miss an anomaly that is detectable by sampling surface soils at the same intervals.

It also seems evident that the area of weathering rock represented by each soil sample is determined by the topographic location of the sample. Soil samples collected on ridges or hilltops represent weathering of the rock immediately underneath. Samples spaced at fairly close intervals, say about 50 feet, along traverses run along ridge crests and across hilltops should give a fairly accurate indication of the ore metal content along the traverse. If any important veins are crossed they will probably give a strong anomaly, and the semi-quantitative field methods of analysis will probably be adequate for analyzing all samples.

About 50 field-type analyses can be made by one man per day, which is

about the same rate at which a field man can collect samples at 50-foot intervals along a traverse. If the samples are spaced 50 feet apart, 2,500 feet of traverse can be covered daily by the two-man team.

Samples collected at the base of ridges and in the bottom of valleys will represent the weathering of materials from a large area tributary to the sample site. Because each sample represents materials from a large area samples can be spaced at relatively wide intervals. If the valleys of the area to be prospected are readily accessible, a convenient system of sampling may be to collect samples in pairs on opposite sides of the valley just above stream level and about 500 feet distant from adjoining pairs. Any anomaly detected by such sampling can be investigated by collecting samples along traverses or on grids uphill from the discovery sample site.

Laboratory-type analytical methods may be necessary for analyzing soil samples collected near the bottom of valleys, because the high dilution factor may cause anomalies of considerable economic importance to be relatively small and difficult to detect. However, the additional labor required for collecting and for analyzing such widely-spaced samples may be compensated by the greater area covered by each sample, as compared to the ridge-crest sampling method.

SUGGESTIONS FOR FUTURE WORK.

The results of this and other studies of geochemical prospecting by soil analysis seem favorable enough to encourage additional investigation. The same kind of investigation could be repeated for other metals or for other climates. In addition, many possible modifications could be tried in the manner of collecting and sieving samples, in the mode of digestion, and in the manner of determination, in order to discover how the techniques can be improved for locating and mapping anomalies. It is also evident that studies could be made of sulfate, soil pH, soil oxidation potential, and other measurable chemical attributes, that may have possibilities as prospecting methods.

Of even greater importance, it seems highly advisable to correlate soil studies more closely with geologic, geophysical, and geobotanical studies so that these various prospecting techniques can be compared and evaluated. Such comparisons seem prerequisite for revealing the advantages and disadvantages of each technique and for combining these techniques with maximum effectiveness in a given prospecting program.

U. S. GEOLOGICAL SURVEY,
DENVER FEDERAL CENTER,
DENVER 14, COLORADO,
March 20, 1952.

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RADIOACTIVITY OF WATERS ISSUING FROM SEDIMENTARY ROCKS.[1]

STANKO MIHOLIĆ.

ABSTRACT.

Radioactivity has been determined in a number of Jugoslav mineral waters issuing from sedimentary rocks. Waters from Carboniferous and Cretaceous strata show a distinctly higher radioactivity than those issuing from sediments belonging to other periods. The possibility of a biogenic accumulation of uranium by organisms particularly abundant in the Carboniferous and Cretaceous is pointed out.

IT is generally accepted that strongly radioactive waters issue primarily from crystalline rocks, particularly granites, but already in 1907 F. Dienert and E. Bouquet [2] found a marked radon content in waters from Cretaceous strata. This varies considerably from point to point within the same formation and is also subject to marked changes during the seasons of the year. G. Muchemblé [3] pointed to the fact that the radioactive waters of Northern France all issue from Carboniferous strata. Helium, another product of radioactive decay, was found by A. Lepape [4] to be particularly abundant in waters issuing from Triassic sediments, which fact he explains [5] by supposing a biochemical accumulation of francium in the plants whose remains are contained in the sediments. As all known α-emitting isotopes of francium are very short-lived (the longest-lived Fr^{221} has a half-life of only 4.8 minutes), its accumulation in plants is not possible and another source of radioactivity has to be looked for. Investigation of waters issuing from different geologic formations in Slovenia, Croatia, and Montenegro have shown that particularly waters from Carboniferous and Cretaceous strata show a remarkable content in radon. This points to a local accumulation of uranium, possibly of a biogenic origin.

As the average content of uranium in the upper part of the lithosphere amounts to 4 ppm, any content of uranium that considerably surpasses this quantity must be considered as an accumulation. In fact, a number of biogenic deposits show uranium contents that are decidedly higher than the average content of the lithosphere. Another interesting point is that such accumulations occur in deposits belonging to definite geologic periods.

[1] This paper was presented in abstract at the International Congress of Pure and Applied Chemistry in New York, September, 1951.

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[4] Lepape, A., Sur l'origine de l'hélium des gaz naturels. Localisation des gisements des gaz naturels les plus riches en hélium dans les dépôts lagunaires anciens: Compte rendu, 199, pp. 1643–1645, 1934.

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There is first thucholite, a carbonaceous mineral rich in uranium, whose occurrence are largely restricted to the Archaean. A sample of thucholite from the Boliden mine, Sweden, gave 10.5 percent uranium.[6] In discussing the mode of formation of thucholite, W. Vernadsky [7] points out that the mineral might have been formed through the action of α-emitting radioactive elements on gaseous hydrocarbons. Here, uranium would be the primary element. It is, however, possible that the reverse is the case and that organisms accumulated uranium using perhaps its nuclear energy in their life processes. Archaean coals of Sweden also contain remarkable amounts of uranium (0.008–0.040%).[8]

The same is the case with the Cambrian black shales of Scandinavia, which all contain uranium although in smaller amounts. In those from the Oslo area 25–180 ppm of uranium was found,[9] and the Swedish alum shales contain 10–200 ppm.[10] A specimen of Lower Silurian Dictyonema shale of northwest Russia showed a content of 53 ppm of uranium.[11] The Dictyonema shales of Belgium contain, according to G. Muchemblé,[12] 9.3 ppm of uranium, and the Carboniferous black schists of northern France and Belgium contain 7.7–36.3 ppm of uranium. She points out, however, that the Carboniferous limestones contain much less uranium (2.2–2.3 ppm.). In the Triassic bituminous shales of southeast Switzerland 12–96 ppm of uranium was found [13] and the Triassic limestones of Austria contain 1.3–55.6 ppm.[14]

The accumulation of uranium is going on to a certain extent even at present. K. M. Strøm [15] found in the black mud of some Norwegian fjords 13–60 ppm of uranium, and recent corals from the Red Sea contain, according to I. Lahner,[16] 65–103.5 ppm. F. Schemnitzky and W. Grabherr [17] discovered in a peculiar calcareous sinter of some Austrian thermal waters (Badgastein, Hintertux and Kleinkirchheim) formed by the action of *Cyanophyceae,* uranium accumulations amounting to 1–1,000 ppm. Although the highest contents were found in very old sinters, uranium was present even in sinters that could not be older than 20 years.

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[12] Loc. cit. The data given in the paper for radium have been recalculated to uranium.

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[15] Loc. cit.

[16] Loc. cit.

[17] Schemnitzky, F., and Grabherr, W., Ueber uran anreichernde warzen- und knöpfchensinter an österreichischen thermen, insbesondere in gastein: Österr. Mineralog. Mitt. Gesell., 112, pp. 13–38, 1951.

Investigations by C. S. Piggot and Wm. D. Urry [18] on the calcareous blue muds and Globigerina oozes have shown the existence of a possibly biogenic accumulation of ionium, a thorium isotope, and those of H. Pettersson [19] on the manganese nodules from the ocean floor indicated a similar concentration of radium. Radium concentration going on in living organisms (*Lemna*) have been described by B. Brunowsky,[20] who found a concentration of radium 20–500 times as compared with the water in which the plants have lived. This shows that besides uranium, other radioactive elements may play a similar role in the organisms, but both elements, being rather short lived, do not interest us here.

The facts recorded above point to a probability of biogenic accumulation of uranium in certain deposits in the past. The question presents itself, however, why such accumulations take place in particular geologic periods. In 1749 Buffon expressed the view that the global amount of living matter on the earth has remained practically unchanged, an opinion that has recently been put forward by W. Vernadsky.[21] If the total amount of living matter remained unchanged, at least since the Cambrian, the share of different species in it has changed considerably during the geologic past, and as the different organisms accumulate different elements in their bodies, the mineral constituents of their remains will be different in different geologic periods.

The age of the strata from which the investigated springs are issuing, was determined geologically from the outcrops. However, an endeavor was made to determine whether the water in question really flows through them for the greater part of its course. A complete chemical analysis of the water has, therefore, been made in most cases.

The total α-activity of the mineral waters due to Rn, Ra A and Ra C was determined using a ionization chamber provided with an electrometer according to Wulf. The radon from the mineral water was circulated through the chamber by means of an atomizer. The measurements were made three hours after the radon was circulated through the system, and the discharge of the electrometer due to background ionization subtracted from the total discharge. From the value thus obtained (I_{max}) the amount of radon in Mache-units was calculated by a modified formula [22]:

$$\mathrm{Rn} = \frac{I_{max}\, C \times 1{,}000\,(l_1 + l_2 + l_3)}{60 \times 500 \times l_3}\left(1 + \delta_T \frac{l_0}{l_1}\right)\frac{1{,}000}{300}\frac{1}{\alpha}.$$

In this expression C is the capacitance of the ionization chamber with the electrometer (3.55 cm), l_0 the volume of the mineral water (500 ml), l_1 that of the air in the flask (750 ml), l_2 the volume of air in the connections, etc.

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TABLE I.

RADIOACTIVITY OF MINERAL WATERS FROM SEDIMENTS.

Source	Geologic age	Temp. °C	Chemical composition in ppm											Radioactivity	
			Na	K	Ca	Mg	Fe	Al	Cl	SO_4	HCO_3	H_2SiO_3	Total solids	Mache units	mμC/l
Dobrna	Triassic	33.2	5.1	1.1	73.6	21.9	0.1	0.2	2.0	23.1	316.3	7.7	451.1	1.66	0.604
Medijske Toplice	Triassic	23.6	3.6	2.6	46.5	27.7	0.1	0.3	1.9	3.8	286.3	4.0	376.8	1.09	0.397
Rimske Toplice	Carbonif.	32.6	5.7	3.0	45.2	26.8	1.6	5.0	1.8	26.9	254.8	1.3	372.1	9.87	3.69
Tuheljske Toplice	Triassic														
Cliff Source		32.4												1.23	0.448
Swamp Source		31.0	11.6	3.1	63.2	37.9	0.3	0.4	3.0	38.2	364.8	80.5	603.0	1.23	0.448
Krapinske Toplice	Triassic														
Jacob's Bath		39.1	9.3	2.3	56.8	32.1	0.6	0.2	2.9	41.0	306.0	28.7	479.9	0.563	0.205
Popular Bath		41.4												0.696	0.253
Stubičke Toplice	Cretaceous														
Main Source		53.4	24.0	6.1	65.9	23.1	0.1	0.7	9.6	85.2	265.0	60.6	540.3	3.16	1.15
Maximilianeum		36.7												3.64	1.32
Source at the Weir		30.7												19.99	7.27
Podsused	Triassic	17.2	10.9	0.9	81.2	39.2	0.1	0.2	6.5	11.0	449.1	28.3	627.4	1.19	0.432
Sv. Ivan Zelina	Cretaceous														
Main Source		24.1	19.3	2.0	118.0	11.2	0.2	0.4	7.0	49.7	394.5	17.1	619.4	6.69	2.44
Well No. 1		24.1												8.42	3.07
Well No. 2		24.1												5.57	2.03
Well No. 5		24.2												6.79	2.49
Čateške Toplice	Carbonif.	51.4	8.6	3.1	52.0	26.0	0.1	0.4	2.7	34.4	268.6	42.9	438.8	10.72	3.90
Sv. Helena	Carbonif.	26.0	83.7	8.0	100.7	37.2	0.1	0.3	65.8	175.8	391.3	36.1	899.0	1.97	0.541
Toplica near Sv. Jana	Triassic	24.7	2.6	1.8	66.4	33.3	0.2	0.5	2.9	10.9	360.5	18.0	497.1	3.55	0.975
Lešće	Cretaceous														
Bath		34.0	5.2	0.9	88.1	31.5	0.2	0.1	3.5	147.4	246.3	16.9	540.1	3.58	1.30
Source on the Meadow		29.2												4.31	1.57
Istarske Toplice	Cretaceous	34.5	703.2	23.4	318.8	85.9	0.8	0.2	1,588	410.5	241.7	40.8	3,476	47.3	16.8
Vretenica (Island of Krk)	Cretaceous	12.2	13.5	3.0	87.2	7.7	0.1	0.5	15.7	18.1	294.9	18.1	458.8	1.45	0.530
Split	Eocene	21.3	8,793	366.1	1,000	563.1	0.7	1.6	15,580	2,220	143.6	3.8	28,670	0.719	0.256
Glavice near Sinj	Eocene	13.7	24.1	10.3	632.4	35.1	0.3	0.9	10.4	1,460	309.2	10.0	2,493	0.248	0.088
Mokošica	Eocene	16.4	3,846	310.4	439.5	354.0	0.6	0.5	7,232	1,038	36.6	11.3	13,270	6.58	2.40
Ulcinj	Eocene	14.1	1,084	151.8	237.0	131.3	1.1	0.2	2,051	499.7	329.5	9.6	4,495	1.90	0.693

(250 ml), l_3 that of air in the ionization chamber (1,000 ml), δ_T the coefficient of distribution of radon between air and water at the temperature T, and a the coefficient of the destruction of radon during the time that has elapsed between the taking of the sample and the measurement of its radioactivity.

The value obtained for radon from this formula has to be corrected [23] in order to take into account the fact that not all of the α-particles are fully effective in ionizing the air in the ionization chamber employed, which had a surface of 600 cm^2 and a volume of 1,000 cm^3. The correction in this case amounts to 1.52. To obtain the total α-activity the value has to be further increased by the factor 2.26.[24] Thus the corrected value for the total radioactivity is

$$E = \text{Rn} \times 2.26 \times 1.52 = \text{Rn} \times 3.42.$$

The results are shown in Table I.

From the data in the table the average radioactivity of mineral waters issuing from sediments of different age was calculated and found to be: Carboniferous 7.52 Mache units, Triassic 1.80 Mache units, Cretaceous 10.08 Mache units and Eocene 2.36 Mache units. There is a distinct maximum of radioactivity in waters issuing from Cretaceous sediments with a secondary maximum for the Carboniferous.

10 Svibovac,
Zagreb, Croatia.

[23] Duane, A., and Laborde, A., Sur les mesures quantitatives de l'émanation du radium: Compte rendu, 150, pp. 1421–1423, 1910.

[24] Gübeli, O., and Kolb, W., Ueber die emanationsmessung als analytische untersuchungsmethode: Helvetica Acta Chimica., 33, pp. 1526–1534, 1950.

LANDSLIDES AND RAPID-FLOWAGE PHENOMENA NEAR PIERRE, SOUTH DAKOTA.[1]

DWIGHT R. CRANDELL.

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ABSTRACT.

Deposits resulting from mass-wasting processes along the Missouri River trench near Pierre, South Dakota, have been studied and mapped. Landslides in Pierre shale are typically of the slump variety in which the surface of movement is concave and in which movement is chiefly rotational. Landslides in glacial drift are mostly of the debris-slide type, although in favorable topographic positions, unit blocks of drift evidently have moved laterally on gently sloping, relatively flat surfaces. Deposits due to rapid flowage are less conspicuous than slumps but have as great or greater areal distribution.

INTRODUCTION.

In the course of geologic mapping in the Pierre quadrangle, South Dakota, the author soon became aware of the great quantities of mass-wasted material in that area. Almost nowhere can contacts between members of the Pierre shale, and between subdivisions of glacial drift, be followed for more than a few hundred yards before the contact is found to be either displaced by a landslide or covered by the deposit of some other mass-wasting process. It is estimated that at least 75 percent of the material exposed in the walls of the Missouri River trench and its tributaries has been moved to some extent by landsliding. Small slides, not more than a year old, can be seen on the slopes of nearly every stream valley in the area. Because landslides are so abundant,

[1] Publication authorized by the Director, U. S. Geological Survey. This paper is part of a dissertation presented for the degree of Doctor of Philosophy in Yale University.

a study of these features was made by the author, assisted by D. W. Hammerquist and E. W. Perkins, during the summer of 1950. About 10 days was spent mapping the slides that are illustrated in this paper, and which represent, as nearly as possible, the several types of landslides that occur along the Missouri River trench in central South Dakota. These landslides are in the northwest part of the Pierre quadrangle (Fig. 1).

The most notable topographic feature of the Pierre area is the Missouri River trench, which is 2 to 4 miles wide and, in most places, 300 to 400 feet deep. When approaching the Missouri from the east, one is not aware of its presence until he is within a mile or two, or in places a few hundred yards,

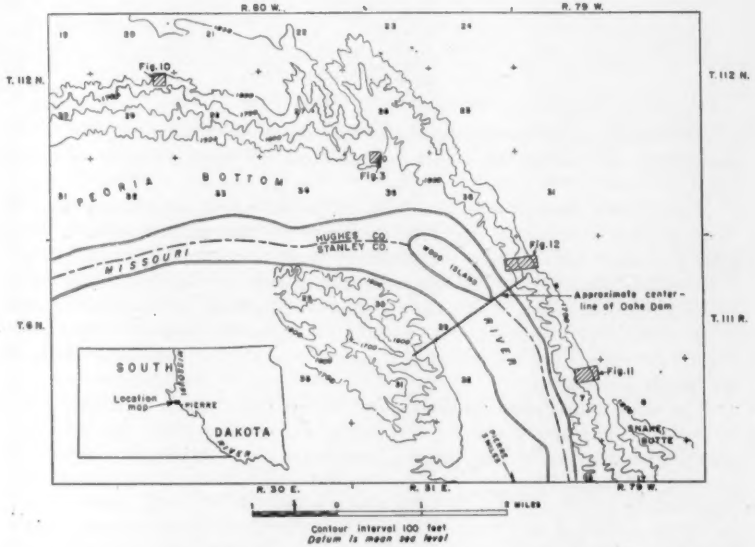

FIG. 1. Location map of slump areas figured in paper. Base is U. S. Geological Survey topographic map of the Pierre quadrangle.

of the trench rim. This characteristic of being deeply incised into a gently rolling upland of little relief makes the term "trench" particularly appropriate.

The Missouri River trench separates the region into two geologically dissimilar parts. South and west of the trench, the upland surface is underlain predominantly by members of the Pierre shale of Late Cretaceous age. The upland north and east of the Missouri is gently rolling Wisconsin ground- and end moraine. Whereas Pierre shale crops out in the trench wall from the Missouri River floodplain up to the upland surface west of the Missouri, glacial drift ranging in thickness from a few feet to more than 150 feet overlies the shale in the north and east trench wall.

PIERRE SHALE.

The only bed rock exposed in the area is Pierre shale. In general, this formation hardly deserves the name shale. Parts of some members are shale in that they are fissile or laminated, but in central South Dakota the formation is predominantly mudstone and claystone.[2] The term Pierre shale will be used in this report as a formation name rather than as an overall description of the lithology of the formation.

The Pierre shale of central South Dakota is subdivided (1) [2a] into 8 members as follows:

Elk Butte member (at top)
Mobridge member
Virgin Creek member
Verendrye member
DeGrey member
Crow Creek member
Gregory member
Sharon Springs member (at base)

The DeGrey and Verendrye members crop out in the part of the Pierre quadrangle with which this paper is concerned. They are briefly described below.

The DeGrey member is predominantly light olive-gray, moderately siliceous shale and claystone. The upper 30 to 35 feet of the member contains 25 or more bentonite beds ranging in thickness from a fraction of an inch to 10 inches and is, therefore, informally referred to as the shale-and-bentonite facies of the DeGrey member. The lower part of the member contains fewer than 10 bentonite layers scattered sporadically through a thickness of 125 to 130 feet. This lower part is informally referred to as the siliceous-shale facies of the DeGrey member.

The shale-and-bentonite facies crops out as a succession of steps formed by resistant shale and claystone alternating with non-resistant bentonite and bentonitic mudstone or claystone. This facies is extremely susceptible to slumping. The siliceous-shale facies commonly stands in near-vertical outcrops where streams have cut steep-sided banks. It is comparatively stable and after prolonged weathering and erosion the facies forms smooth slopes. The upper beds of the DeGrey member grade into the overlying Verendrye member. The contact is marked in a general way by a transition from step-forming shale, claystone, and bentonite layers of the DeGrey member to smooth slopes underlain by claystone and mudstone of the Verendrye member.

The Verendrye member consists of 160 feet of light olive-gray mudstone and claystone with a subordinate amount of shale. The member weathers to light olive-gray or brownish-gray gumbo.[3] Because of the gumbo cover,

[2] Shale is a fissile or laminated sedimentary rock of sufficient induration to remain coherent after wetting, and in addition the term shale refers to rocks that contain clay minerals as well as predominantly clay-size material. Claystone is indurated clay that remains coherent upon wetting, but which lacks fissility or lamination. Mudstone is partly indurated clay that disaggregates upon wetting and lacks fissility or lamination.

[2a] Number in parentheses refer to Bibliography at end of paper.

[3] The term gumbo, as used here, refers to clayey material that is granular and tough when dry and very slippery and plastic when wet.

which is from several inches to several feet thick, readily visible stratification is lacking on outcrops. The member forms smooth slopes wherever it is exposed. It is subject to extensive slumping.

GLACIAL DRIFT.

The standard Pleistocene sequence used in this paper is as follows:

Pleistocene series	Wisconsin stage	Mankato substage
		Cary substage
		Tazewell substage
		Iowan substage
	Sangamon stage	
	Illionian stage	
	Yarmouth stage	
	Kansan stage	
	Aftonian stage	
	Nebraskan stage	

Because no pre-Wisconsin glacial drift has been identified in the Pierre area, and because the area lies nearly 20 miles west of the westernmost Cary drift (3), it is assumed that all the glacial drift belongs to the Iowan and Tazewell substages of the Wisconsin stage. Although numerous glacial erratics on the upland west of the Missouri River indicate that one or more ice sheets crossed the trench, the almost complete absence of till west of the river suggests that the trench served as an efficient trap for most of the basal load of the glacier or glaciers that crossed it. The glacial drift is predominantly clayey till with local layers of sand and gravel. The wide range in thickness of the glacial drift exposed along the north and east wall of the trench is caused chiefly by large irregularities in the bed rock surface formed by stream erosion and mass-wasting before the Wisconsin stage. The glacial drift filled these irregularities to form an essentially flat upland surface east of the Missouri River.

CLASSIFICATION OF LANDSLIDES.

The most convenient classification of landslides is that of Sharpe (7), who defined these features as "perceptible downward sliding or falling of a relatively dry mass of earth, rock, or mixture of the two." The lack of included water distinguishes the landslide from rapid-flowage phenomena which include the debris avalanche, mudflow, and earthflow. Sharpe further subdivided landslides as shown below, according to rate and character of movement and according to the kind of material involved in the slide. Landslides in the Pierre area can be subdivided into slumps and debris-slides according to the same characteristics.

Rate of movement	Earth or rock, dry or with minor amounts of ice and water
Slow to rapid	Slump
Very rapid	Debris-slide
	Debris-fall
	Rockslide
	Rockfall

SLUMPS.

Slump is the downslope movement, or rotation with little downward sliding, of a mass as a unit or as several subsidiary units. This definition is essentially the same as that given by Sharpe (7, p. 65). In his definition, Sharpe specified that movement of slumps was "usually with backward rotation on a more or less horizontal axis parallel to the cliff or slope . . ." from which the slump block was derived. The surface of movement of slump blocks is typically concave. Terzaghi (8, p. 177) implied that he considered the curved

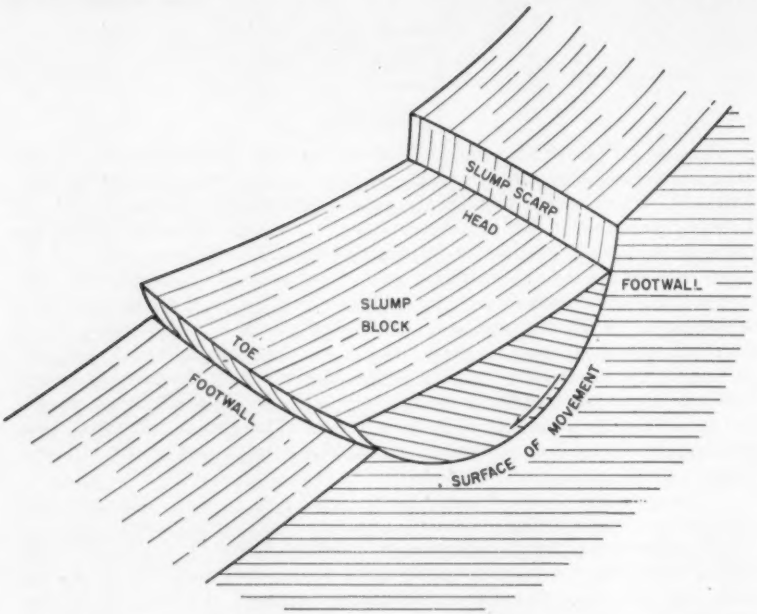

FIG. 2. Components of a slump.

surface of rupture essential to this particular class of landslide, which he called "shearing slide." The present writer recognizes the common occurrence of a curved surface of movement in slumps in the Pierra area, and in landslides described in the literature. Restriction of the term slump to landslides having curved surfaces of movement, however, leaves an important landslide type without a convenient varietal name. Movement of a large unit block of material on a relatively flat surface with little or no backward rotation appears to correspond to the definition of slump more closely than to the alternative described by Terzaghi as detritus slides, which are "simple flow phenomena."

Terzaghi (10, p. 182) noted that, on curved surfaces of movement, the

radius of curvature of the surface is least at the upper end, greatest in the middle, and intermediate at the lower end. Therefore, the curve resembles an arc of an ellipse.

In order to avoid misinterpretation of the feature to which reference is made, the components of a slump are represented in Figure 2.

Slumps in the Pierre area are here discussed according to the material

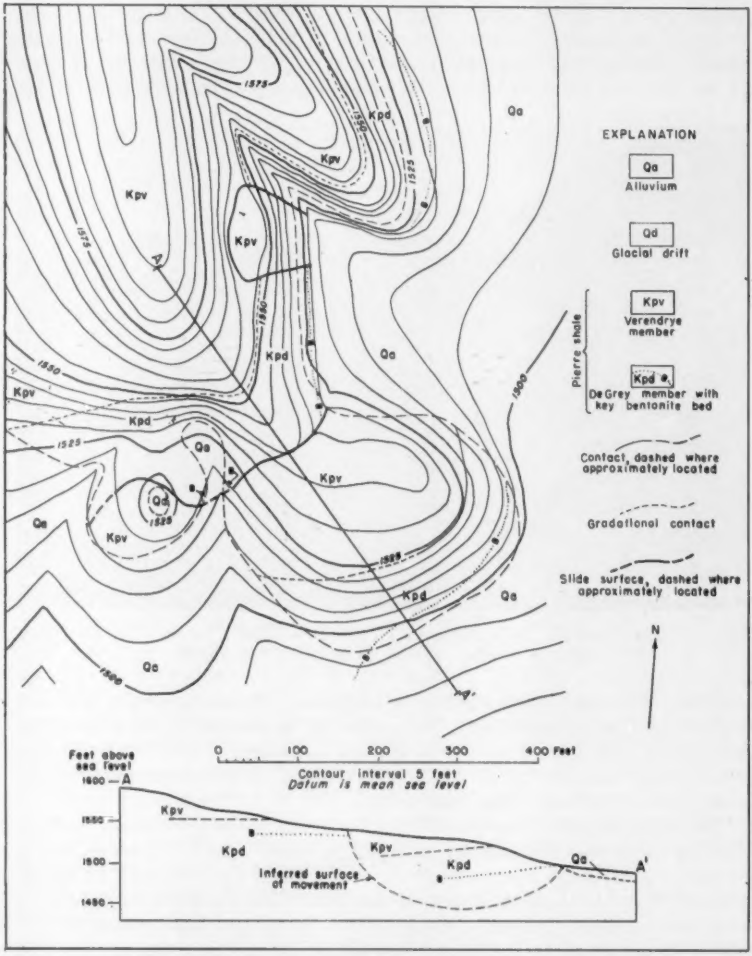

FIG. 3. Slump in Pierre shale in the NE¼NW¼ sec. 35, T 112 N, R 80 W.

involved in movement for convenience of reference rather than with the intention of proposing that a genetic difference exists among them. The examples of slumps noted are those that involve Pierre shale, those in which glacial drift is the predominant constituent, and landslides in which both shale and glacial drift have moved.

1. A slump in which Pierre shale is the only constituent is located in the NE¼NW¼ sec. 35, T 112 N, R 80 W (Fig. 3). This landslide illustrates the concave surface of movement characteristic of slumps in Pierre shale. It will be noted on the cross section that if the DeGrey-Verendrye contact in the slump is restored to a horizontal position, there is a vertical difference of about 15 feet between that contact and the same contact in the shale that has not

FIG. 4. Slump scarp at west abutment of the Oahe Dam. Picture taken in June, 1951, 9 months after reactuation of the slump.

slumped. It is not known whether this relation indicates that there is a fault in the shale that coincides with the surface of movement at the back of the slump block, that there was some downslope movement in addition to rotation of the slump block, or that the configuration of the actual surface of movement is not correctly shown in the cross section.

The slide probably was caused by an unequal stress distribution brought about by excavation from the toe of the original valley wall. At some time in the past, the Missouri River occupied a course along the north side of Peoria Bottom (Fig. 1). Lateral erosion by the river formed a steep valley wall in which the necessary conditions were met for slumping. Bank-cutting of this nature, accompanied by landsliding into the Missouri River, can be observed today along many segments of the Missouri trench.

A dormant slump of the same variety was reactuated in August 1950, near the west abutment of the Oahe Dam. The old landslide is in the SE¼SW¼ sec. 30, T 6 N, R 31 E. During excavation a large quantity of shale was removed from the toe of the slump block. Movement of the block started and work in the area was temporarily halted. Measurements by the Corps of Engineers indicated that movement was progressing at the rate of 1 to 1½ inches in 24 hours. After 10 months of movement, the total vertical displacement at the head of the slump block was about 18 feet (Fig. 4). The slump block was excavated along the surface of movement for a distance of about 5 feet at the toe and at the head. At both these places the surface of movement dipped about 40° toward the slump block.

The common occurrence of slumps in the Pierre shale was noted by Pesonen and others (5, p. 52) in connection with a study of the manganese-bearing DeGrey member near Chamberlain, South Dakota. The following paragraph is taken from their discussion of landslides.

> Most slides seen in the bucket-drill holes consist of a single fracture along which the movement occurred. The shale adjoining the fracture frequently was closely jointed to depths of 1 to 2 feet. The slides have moved as blocks rather than as avalanches, for the shale above the slide seldom appeared to have been badly contorted by the movement. Some slides have a thin layer of bentonite drawn out along the fracture. Many slides have moved horizontally along the top of the Crow Creek marl. The vertical components of the displacement of 44 major slides range from 5 to 75 feet and average 29 feet. The horizontal components of the displacements range from 6 to 950 feet and average 110 feet. Frequently the fractures of the displacement are spaced a few feet to 50 feet apart and make a complicated mozaic [*sic*]. An area measuring about 150 by 200 feet was mapped in detail near the Bureau of Mines experimental plant. It contained 14 slides, and along these the displacements varied from a few feet to more than 25 feet. The horizontal distances between the slide surfaces that were subparallel ranged between 3 and 100 feet.

A group of representative slumps figured by Pesonen are shown in Figures 5 and 6. In each case, terminology of the shale members has been changed to correspond to the present usage of the U. S. Geological Survey.

An interesting, but quantitatively unimportant, variety of slump in Pierre shale has been noted in several places near Pierre. This consists of unit blocks of shale that have moved down over the slope below, completely vacating their original position, but preserving their continuity without internal disturbance other than plastic bending. The most readily accessible example is in the center sec. 36, T 112 N, R 79 W. Here a tabular mass, nearly 5 feet thick, consisting of beds in the shale-and-bentonite facies of the DeGrey member, has slid into a gully. In view of the evident unit movement of this mass of shale, claystone, and bentonite, it probably was plastic at the time of movement. The presence of a bed of bentonite at the base of the mass undoubtedly facilitated the unusual behavior of this slump.

Slumps in shale can be recognized in several ways. In the Pierre area the Pierre shale, for the most part, is horizontal or nearly so. Most exposures of inclined beds, therefore, can be taken as evidence of slumping. Local vertical displacement of key horizons, such as distinctive bentonite beds, and abrupt

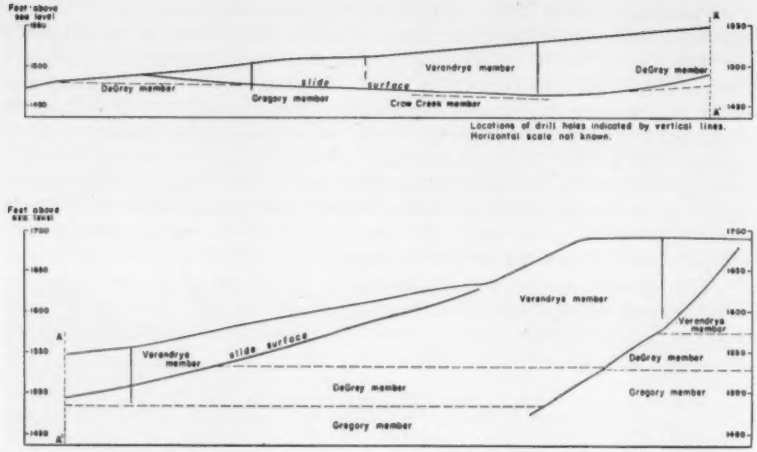

FIG. 5. Slump in Pierre shale near Oacoma, South Dakota. (After Pesonen, 5.)

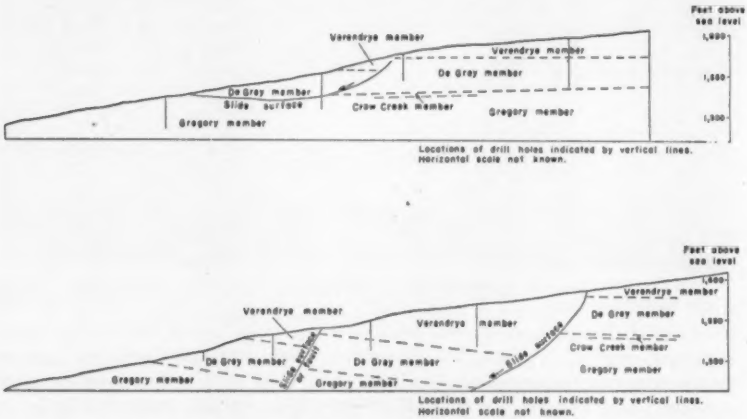

FIG. 6. Slumps in Pierre shale near Oacoma. (After Pesonen, 5.)

lateral changes in color or lithology, can also be used for the recognition of slumps. Although proof is lacking in most exposures, the shale is also cut by faults of less than 30 feet vertical displacement. Generally it is impossible to distinguish between rupture surfaces related to mass-wasting movements and faults caused by warping.

2. A slump involving glacial drift is located in the NE¼ sec. 29, T 112 N, R 80 W (Figs. 7, 8). The large block of glacial drift, the volume of which is

between 300,000 and 400,000 cubic yards, moved southward as a unit mass, tilting very little in so doing. If it is assumed that the contact between till and sand gravel originally was essentially horizontal, there appears to have been less than 25 feet vertical displacement in the slump.

When this slump was studied in 1950, it was inferred that the block of

FIG. 7. Slump in glacial drift north of Peoria Bottom.

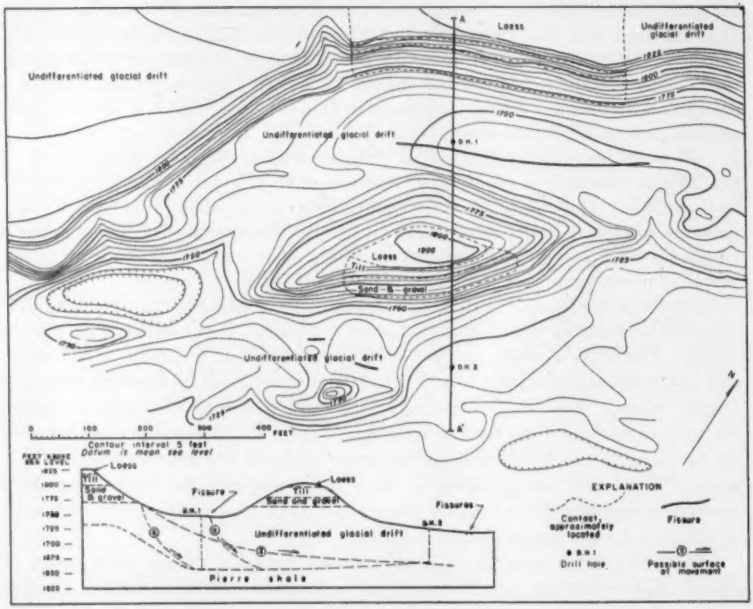

FIG. 8. Slump in glacial drift in the NE¼ sec. 29, T 112 N, R 80 W, north of Peoria Bottom.

drift had slid outward on a shale surface sloping more or less uniformly south toward the Missouri River (2). In October, 1951, several power-auger holes were drilled in the landslide area. In the drill hole marked D.H.2 on Figure 8, a 6-foot zone of saturated till was encountered at a depth of 52 feet, immediately overlying the till-shale contact at a depth of 56 feet (altitude 1,665 feet). As the auger brought the water-soaked material to the surface, the mud spread out on the ground as a fluid mass with low viscosity. In drill hole D.H.1, shale was encountered at a depth of about 90 feet (altitude about 1,655 feet). The 10-foot difference in altitude of the shale surface in these two drill holes might refute the hypothesis that the shale surface slopes southward. On the other hand, it is possible that the difference is a result of inaccurate logging. If the shale surface slopes northward in the slump area, it seems likely that the principal surface or zone of movement is within the glacial drift (surface marked Z on cross section, Fig. 8). If the shale surface slopes southward at a low angle, the main slip surface probably coincides at least locally with the shale-drift contact (possible slip surface marked X on cross section, Fig. 8). The abundance of water at this contact strongly suggests that the movement has taken place along this contact.

Geologic mapping of the north wall of the Missouri River trench immediately adjacent to this landslide area indicates that the unslumped contact between glacial drift and Pierre shale lies at an altitude of about 1,730 feet. It is inferred that the shale-drift contact is at the same altitude immediately north of the landslide area, and that the difference in altitude between this contact and the shale-drift contact in drill hole D.H.1 represents the slope of a pre-drift valley wall. The possibility that this 75-foot difference is principally related to vertical displacement on a slump in the shale has been considered. It was noted above that the vertical displacement of the large slump block of glacial drift probably is less than 25 feet and that little or no rotation occurred in this block. If there is a rotation-type slump in the shale, this slump is apparently unrelated to the predominantly lateral translation of the slump block of glacial drift. It seems probable, although not certain, that shale is not involved in movement in this landslide area.

Cracks in the ground surface noted on Figure 8 indicate that this landslide area has been active within the past several decades, if not within the last ten years. The largest crack mapped ranges from 1 foot to about 5 feet deep, and is continuous throughout a distance of 450 feet. It is inferred that this fissure extends downward to the principal surface or zone of movement along the surface marked Y on the cross section, Figure 8. There is no evidence of an incipient slump block developing today back of the northernmost slump scarp. This might be an effect of the configuration of the underlying shale surface, or might indicate that the glacial drift is in temporary equilibrium with conditions of slope and moisture supply.

The alternative explanation of the notable isolation of this large block of glacial drift by stream erosion has been considered. This hypothesis appears to be not valid because of the absence of valleys or gullies implied by such erosion. Runoff in the area mapped drains mostly into closed depressions.

Moreover, the cracks in the ground surface indicate that relatively recent lateral movement of the block of drift has occurred.

The saturated character of the shale-drift contact indicates that frictional resistance in this zone is essentially negligible. Indeed, it seems remarkable that downslope movement is not now taking place. The probable reason for the apparent stability of the landslide area is the presence of adequate toe restraint.

The slumped block of glacial drift is adjacent to the proposed reservoir behind Oahe Dam, so the effect of a permanent body of water on landslide areas adjacent to it should be considered. The altitude of the proposed water level in the reservoir is about 75 feet below the bottom of the slump block. The area mapped in Figure 8, however, is but a very small part of a larger area of landsliding that continues without interruption down the valley wall to well below the proposed reservoir level. It might be anticipated that saturation of reservoir walls, a rise of the water table in areas adjacent to the reservoir, changes in the altitude of the water surface, and wave erosion on the shoreline, will cause downslope movements of this landslide area, affecting not only the material now present on the side of the trench, but possibly also causing recession of the scarp bordering the upland to the north.

The effect of the water table upon slope stability has been described by Hennes (4, pp. 40–41). He noted that, in some situations, an increase in

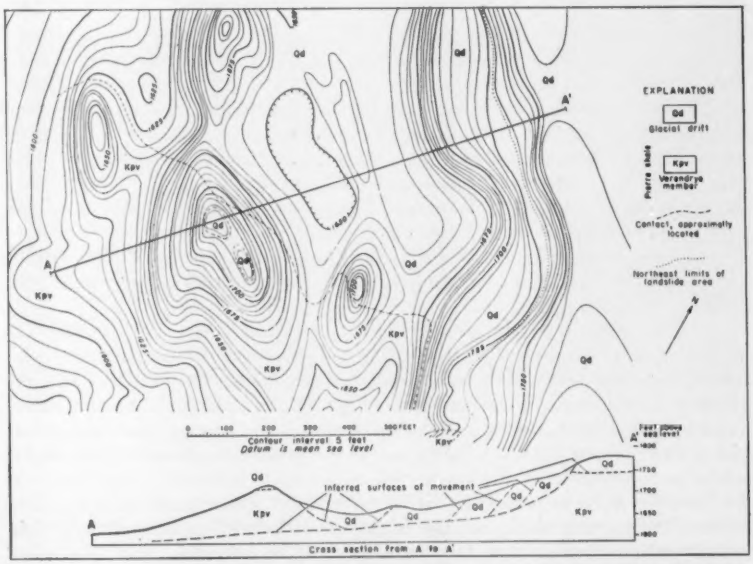

FIG. 9. Slumps in glacial drift and Pierre shale in the NE¼ sec. 35, T 111 N, R 79 W, north of Snake Butte.

the height of the water table will be accompanied by a decrease in slope stability. It seems likely that the creation of a large body of standing water in the Missouri River trench will raise the water table of the surrounding area. The effect of this might very well be to reactivate large areas of now-dormant landslides along the walls of the reservoir and to cause extensive scarp recession along the valley walls.

3. A third slump variety is included in a landslide area along the east wall of the Missouri trench north of Snake Butte. As noted on the geologic map (Fig. 9), part of this slump encompasses both Pierre shale and glacial drift, which here is predominantly till. Evidently, the surface of sliding does not here correspond to the shale-drift contact. No inclined strata in the slumped blocks of shale were noted; possibly this can be attributed to the scarcity of well-defined planes of stratification in this part of the Verendrye member, and to a lack of good exposures in all but the westernmost landslide block. The attitude of the shale-drift contacts, however, indicates that rotational movement of the shale blocks has occurred, causing the contact surfaces to dip east and northeast. The relative isolation of the blocks is attributed to lateral movement west and southwest away from the present upland scarp rather than to the removal of material by stream erosion. Very little run-off appears to leave the area in the center of Figure 9 and the lack of large gullies cut into the depression suggests that running water has removed relatively little material from the central depression.

DEBRIS-SLIDES.

The second main type of landslide in the Pierre area is the debris-slide. The definition of this feature given below follows the terminology of Sharpe (7, p. 74). A debris-slide consists of the downslope movement of predominantly unconsolidated and incoherent material, which, as it slides or rolls forward, is broken apart and forms an irregular hummocky deposit. The fragmentation of material in debris-slides serves to distinguish them from slumps in which there is predominantly unit-block movement. Instead of the more or less simple concave surface of movement of slumps, material in debris-slides moves along many small fractures of random orientation. The resulting deposit is characterized by swales and hummocks that resemble end moraine topography (Fig. 10).

Next to slumps involving only Pierre shale, the debris-slide probably is the most abundant landslide type along the walls of the Missouri trench. Areas in which debris-slides are numerous are along the east wall of the Missouri trench north of Snake Butte (Fig. 10), and along the north side of the trench in Peoria Bottom. Smaller areas of this type of landslide occur east of Pierre along the north valley wall of the Missouri. Debris-slides might not be as conspicuous as the slump type of landslide previously described but they involve more area and are of equal practical importance. A map of a debris-slide was not made, because of a general lack of outcrops from which subsurface information regarding the slide could be inferred.

Probably the most common cause of debris-slides is slope failure brought about by the addition of a large amount of moisture during wet seasons.

This moisture increases the weight of the material underlying a slope and thereby somewhat decreases slope stability. More important, the added moisture lowers the stability of the saturated mass by increasing the pore-water pressure, which decreases the shearing resistance of the material (9, pp. 88,

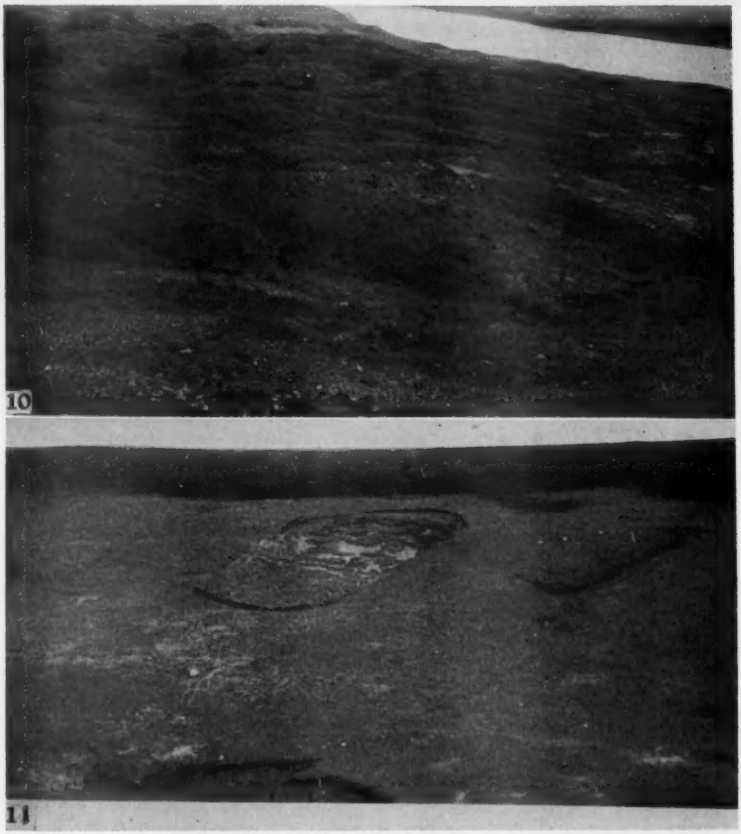

FIG. 10. Debris-slide area north of Snake Butte, Missouri River at right.
FIG. 11. Earthflow in till.

91). It is commonly believed that the added moisture also lowers slope stability by acting as a lubricant. Terzaghi has noted, however, that because sufficient water for the "lubricating action" is nearly always present near the surface of slopes, the increased rainfall does not cause slides by lubricating the soil.

TIME OF ORIGIN OF LANDSLIDES.

Because the movement of landslides is dependent on gravity, slopes sufficiently steep to permit sliding probably did not exist in the Pierre area before the Illinoian stage. In that stage, the area was rejuvenated by the initial cutting of the Missouri River trench. The floor of the trench during the Sangamon stage probably was at least as low as the modern floodplain. A major part of the trench widening probably took place during the Sangamon age by means of landsliding and other mass-wasting processes. In several of the landslide areas previously described, Tazewell till was involved in the movement. Therefore, these slides are at least post-Tazewell till.

Because moisture plays an important role in the development of landslides, it might be inferred that now-dormant landslides began to move at a time in the past when there was greater precipitation than now. The climate was very likely appreciably moister during the maxima of the Cary and Mankato substages. Accordingly, it is suggested that most of the slumping along the walls of the trenches of the Missouri River and its tributaries occurred at these times. No new slumps in which there has been unit-block movement are known to have occurred within historic time.

RAPID-FLOWAGE PHENOMENA.

The types of mass-wasting heretofore described involve a relatively small proportion of water to solid. With an increase in moisture, slopes on surficial material fail by flowage rather than by unit-block movement on well-defined surfaces. Thus there is both downslope movement and internal deformation of the moving body.

In the absence of well-consolidated rock units in the area, there is little question that flowage is a common type of mass-wasting in the Pierre area. A large proportion of the total annual precipitation occurs during spring months when melting snow also contributes moisture to the mantle. Slopes that are stable when dry, are thrown out of equilibrium by water that soaks into surficial permeable material. This water-soaked layer then slides downward and accumulates at the bottom of slopes. This is particularly common on slopes underlain by the Verendrye member of the Pierre shale.

Classification.—Sharpe (7) suggested that rapid-flowage phenomena are intermediate stages between two end members: fluvial transport and landslides. The series is dependent on the water content of the moving mass and on rapidity of movment. According to Sharpe, the gradational series in terms of diminishing moisture is as follows: stream flow, slope-wash, sheetflood, mudflow, debris-avalanche, and landslide. Rapid-flowage phenomena have been subdivided by Sharpe (p. 49) according to the rate of movement as shown below.

Movement	Earth or rock plus water
Slow to rapid	Earthflow
	Mudflow
Rapid	Debris-avalanche

Rapid-flowage phenomena in the Pierre area include earthflow and mudflow. The distinction between the two processes depends on the steepness of the slope and on relative proportion of water to solid. From the character of the resulting deposits, it is inferred that mudflows involve more rapid movement and a greater amount of included water than do earthflows.

Earthflows.—Rogers (6) noted that slope failure by earthflow was characterized by three main divisions: 1) slump-type blocks at the head, 2) a buckled and fissured area in the center, and 3) a bulge at the toe (Fig. 12). Inasmuch as true flowage occurs principally in the lower part of the mass, in the strict sense the term earthflow should not include the upper, slumped portion of the disrupted material.

A typical earthflow in the Pierre area is illustrated in Figure 11. The material involved in flowage is glacial drift that consists predominantly of clay-rich till. It will be noted that this particular earthflow occurred in material that previously had been affected by a mass-wasting movement, the scarp

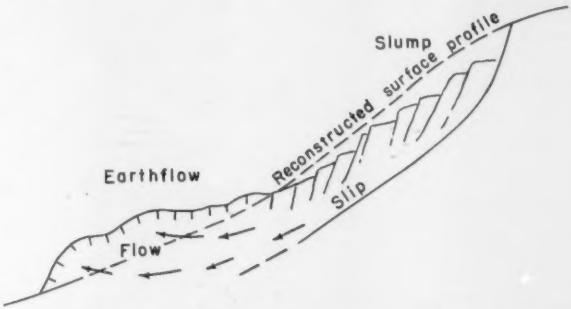

FIG. 12. Cross section showing relation of earthflow to slump. After Sharpe (7, p. 54).

of which is outlined by darker vegetation immediately above the fresh earthflow.

An interesting example of an earthflow was noted in June, 1950, on the side of a highway fill on U. S. Highway 14, about 1 mile northeast of Pierre (Fig. 13). The outlet of a depression, about 1 acre in area, lying north of the highway had been artificially closed before a period of heavy rainfall so that water would accumulate to form a small cattle pond. Water from the pond soaked into the highway fill, which consists of sand, gravel, and Pierre shale. The base of this fill appears to be predominantly reworked shale. A large mass of water-soaked material forming the south base of the fill flowed laterally southward, and by removal of support, caused the upper part of the fill to fail by slumping. When the failure was noted, the cattle pond was drained immediately. The remedy was to replace the slumped material and to decrease the slope of the fill by adding a large mass of weathered Pierre shale.

A slope failure that appears to be intermediate between earthflow and mud-

flow occurred in the spring of 1951. A deep gully in the NW¼NE¼ sec. 10, T 6 N, R 29 E, was filled to a depth of at least 10 feet and probably as much as 20 feet by a mass of weathered shale derived from an outcrop of the Verendrye member of the Pierre shale at the head of the gully (Figs. 14, 16). Slump-type blocks at the gully head indicate the removal of supporting material, and unit blocks of weathered but internally undisturbed shale as much as 6 feet in diameter occur throughout the length of the flow. It is particularly interesting to note that well-developed slickensides, inclined down the gully, occur at the contact of the flow with the adjoining gully walls (Fig. 15). The vertical distance between the top of the slump scarp and the toe of the flow is 85 feet and the lateral distance the flow traveled is about 350 feet.

The flow was first seen early in August 1951. At that time the toe of the flow did not extend beyond the mouth of the gully down which it had moved. This circumstance suggests that the moving mass had considerable internal friction, despite the evidence of low viscosity revealed by the distance the flow traveled down the gully. When the area was revisited in early September after

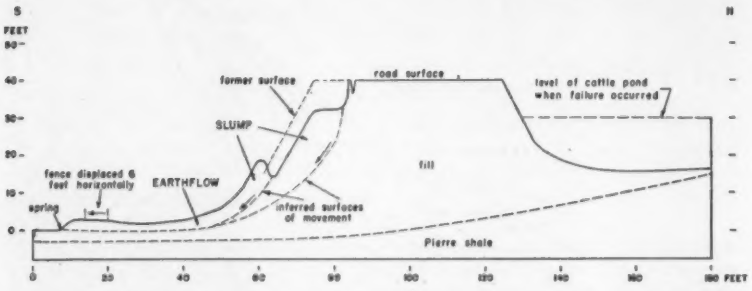

FIG. 13. Fill failure on U. S. Highway 14 about 1 mile northeast of Pierre.

a heavy rain, the toe of the flow had moved from 15 to 20 feet beyond the gully. There is no evidence that the upper part of the flow experienced a renewal of movement at this time.

Mudflows.—Mudflows occur when a permeable fine-grained material is so thoroughly saturated with moisture that it starts to flow downslope as a viscous mass. Thus mudflows are purely flow phenomena whereas earthflows consist in part of movement of unit blocks.

It was noted above that the Verendrye member of the Pierre shale is almost invariably covered with a blanket of cracked and granular gumbo from several inches to several feet thick. When a large amount of water is added to this porous material, a viscous mass is formed that will flow downslope if in a favorable topographic situation. Upon reaching the adjacent valley floor, the mass spreads out and becomes part of an alluvial fan. A mudflow of this type in the NE¼ sec. 15, T 6 N, R 29 E is illustrated in Figure 17. An examination of the head of the gully disclosed a fresh scarp in the lower part of the Verendrye member. Behind the scarp was an extensive body of spongy

gumbo that evidently had had sufficient internal friction to remain in place when the adjacent mass broke loose and flowed down the gully. The rapidity of movement is inferred from grooves that are noticeable on the sides of the gully.

Although in most places fresh evidence of mudflows is lacking, it is very likely that flows of this nature form an important contribution to alluvial fans.

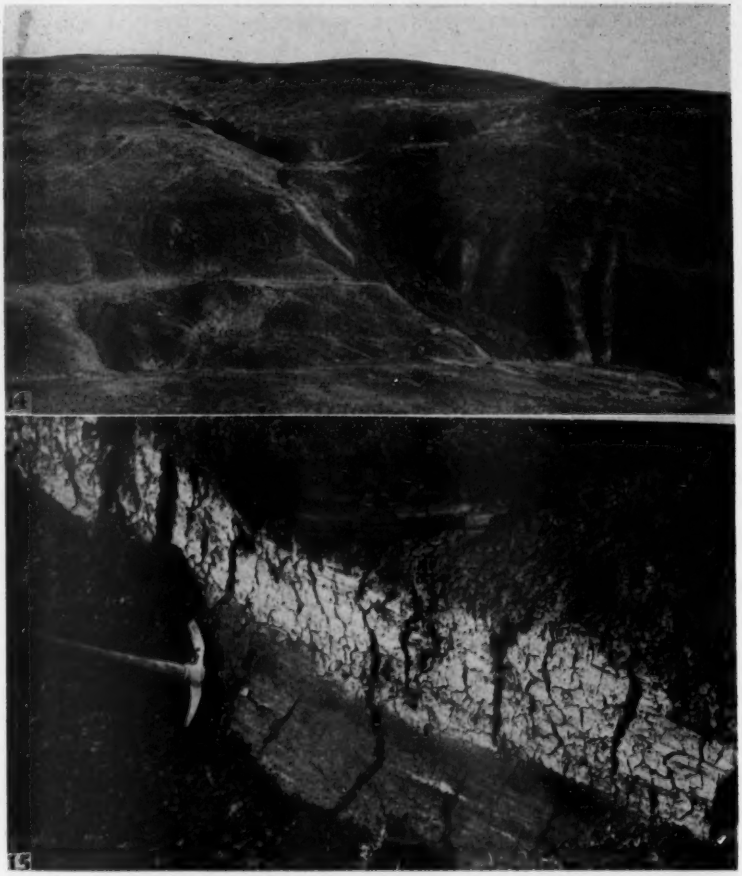

FIG. 14. Flow of weathered Pierre shale in the NW¼NE¼ sec. 10, T 6 N, R 29 E, 4 miles west of the Pierre quadrangle.

FIG. 15. Slickensides formed at junction of flow and gully wall. Pick rests on flow, three fragments of slickensided material came from flow.

FIG. 16. Toe of flow after renewal of movement.
FIG. 17. Mudflow deposit at the mouth of a small gully. Note grooves on gully walls.

Mudflows very likely occur in the other members of the Pierre shale that weather to a porous gumbo similar to that of the Verendrye member.

GENERAL COMMENTS.

Landslides are caused by one or more changes that affect slope stability. These changes are an increased load, a decrease in strength of material, and a less favorable stress distribution. The change in stress distribution might result from steepening a slope, from excavation at the toe of a slope, or by removal of some external support of part of the load. Lateral erosion by running water probably is the most common cause of natural excavation at toes of slopes. This sets up an unequal stress distribution that eventually is balanced by downslope movement of the material.

Many landslides are started or reactuated during or shortly after a rainfall. The movement can be attributed chiefly to an increase in pore-water pressure, which decreases the shearing resistance of the material. The added water also increases the weight of a unit mass and thereby might destroy its equilibrium. Under certain conditions and in some materials the added moisture might act as a lubricant.

The effect of a rise in the water table on dormant landslides or on general slope stability of reservoir walls should be considered where the creation of a reservoir is planned. A rise of the water table will be accompanied by an increase in pore-water pressure to the point where now-quiescent slump blocks might be thrown out of equilibrium. If the level of a reservoir is appreciably lowered over a short period, the effect of pore-water pressure on slip surfaces or on potential surfaces of sliding is amplified and slope stability is thereby greatly decreased.

In the course of investigations of slumps in shale, the writer frequently has noted that in slumps caused by natural processes, such as river-bank cutting, movement generally is confined to one slip surface and internal deformation of the slump block is small. After equilibrium is re-established by movement, the slump block should remain dormant indefinitely if there is no future disturbance of equilibrium. In slumps caused or reactuated artificially by large-scale excavation, many subsidiary slip surfaces appear in the slump block and considerable internal deformation occurs. It is suggested that this relationship results from the amount to which the slump block is thrown out of equilibrium. By bank erosion or small-scale artificial excavation, only a small amount of material generally is removed from a slope in the course of a short period of time. When slope failure occurs, a small amount of rotation usually is sufficient to re-establish stability. Once movement has occurred, material along the surface or zone of movement probably never completely regains its former shear strength, but, in the absence of internal deformation, the slump block should remain a unit and retain its original internal strength.

A different kind of condition results when slope stability is disturbed by the excavation of a relatively large amount of material. Rather than the removal of a few hundred cubic yards of material from a slope during a season, artificial excavation commonly displaces tens of thousands of cubic yards in an interval of a few days. Slope stability is thereby so greatly affected that only large-scale movement will re-establish slope equilibrium. In the course of this movement, warping occurs, subsidiary slip surfaces develop, and the block loses its unit nature by internal deformation. The product is a slump block with low internal strength.

The type of remedy that should be applied to a slump should take into consideration the internal strength of the slump block. In a block of small displacement in which the unit character, and thereby internal strength, is retained, replacement of the excavated toe, plus a safety of perhaps 10 to 20 percent of the original volume excavated, might effectively stabilize the slide. Along with this remedy, open cracks should be filled and tamped, and sodded over in order to prevent infiltration of water along the zone or surface of movement. This remedy involves nothing more than an attempt to re-establish conditions that existed prior to slumping. The sooner such a remedy is applied after initial slump movement, the better will be the chance of permanent stabilization. In a slump block that has been internally disturbed, replacement of toe restraint might serve only to stabilize a portion of the slump. Probably internal deformation of the slump block would continue and would make the filling of fissures a continuous process.

If a slump is allowed to develop until internal deformation has occurred, the ultimate remedy is both costly and difficult. Very probably the only effective remedial measure is to decapitate the slump, and to grade the entire hillside to as low an angle as possible by filling at the toe and cutting upslope from the slump scarp. It seems evident that in a remedy of this type, material should not be removed from the toe of the slump, even in order to establish an overall lower slope ratio.

It was stated above that slump stabilization might be accomplished by excavation at the head of the block. This remedy has a serious drawback: removal of toe support from material behind the slump scarp might cause upslope recession of the scarp. For this reason head excavation generally should be accompanied by grading the slope behind the slump scarp to a ratio known to be stable for the material involved.

U. S. GEOLOGICAL SURVEY,
DENVER, COLO.,
April 10, 1952.

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DISCUSSION

METAMORPHISM OF COAL.

Sir:—In a recent paper on "Metamorphism of Coal" the author, Dr. A. Lahiri,[1] furnishes the reader with some interesting suggestions in regard to the possible nature of coal and coal metamorphism by calling attention to the changes that he believes would take place in a "polydispersed polymeric colloidal system," such as he believes coal to be, under conditions of geologic stress. It is not my intention to question the correctness of Dr. Lahiri's concept of the nature of coal, as he is much better qualified than I to identify a polydispersed polymeric colloidal system. However, in the process of demonstrating the validity of his thesis he makes certain rather novel assumptions in regard to the physical make-up of coal, which are used to help him establish his case. One wonders, therefore, if the usually accepted concepts of the constitution of coal were actually essentially correct what effect this would have on his case.

For example: On pages 258 to 261 under the heading, "Development of Banded Structure," Dr. Lahiri presents an unusual and to the present writer a somewhat dubious explanation of the origin of vitrain bands in bituminous coal beds. It is stated that in lignites "vitrain permeates the whole of the coal substance, whereas in mature coals they (sic) appear as bands." As opposed to this idea numerous references could be quoted but I have selected a recent article by Edwards,[2] in which he presents the facts in regard to the occurrence of vitrain in lignite very positively and clearly. Edwards[3] says:

> The color differences that develop in the coal types as they dry out can also be attributed to the different degrees of decomposition of the woody material in the two coals. It is a feature of much of the wood (logs and stumps) exposed in both the Yallourn and Latrobe seams, that, as it dries, the surface layers develop jet black vitrainous luster. When such a piece of wood is broken, the transition from the vitrainous surface to the wood-like interior is manifest. The black color of well-dried lignitic coal is clearly due to the presence in it of an abundance of this vitrainous substance which is more or less completely absent from the earthy coals.

This quotation is in accordance with the frequent assertion that vitrain represents coalified wood. It also points to the scarcity of vitrain-like material in other than the woody layers of the lignite deposit. "The lignitic coal," writes Edwards (p. 58), "from its resemblance to vitrain, both in chemical composition and appearance when dried out, appears to contain more only partly decomposed woody tissue than the earthy coal."

[1] Lahiri, A., Metamorphism of coal: ECON. GEOL., vol. 46, no. 3, pp. 252–266, 1951.
[2] Edwards, A. B., Coal types in the Yallourn and Latrobe brown coal seams: Australasian Inst. Min. Metallurgy Proc. 146–147, 1947.
[3] Edwards, op. cit., p. 63.

It appears, and this is the relationship between woody tissue and vitrain that is usually favored by geologists and botanists, that vitrain is a residual modification of the woody tissue due possibly in part to desiccation or loss of pore space, which may be essentially the same thing. This transformation, although accompanied by progressive darkening and increasing opacity of the material, does not obliterate the traces of the original cell structure. This transformed woody material represents the conventional concept of vitrain.

In this connection it may be pointed out that commonly isolated logs or splinters of wood that have been buried by themselves in Pennsylvanian sediments have been completely altered to vitrain, although they are definitely separated from any outside peaty source of such material. Such vitrain, moreover, seems from observation to be exactly similar to that composing the vitrain bands in near-by coal beds.

Dr. Lahiri's interpretation of the origin of vitrain in coal beds of bituminous rank seems to the present writer quite unrealistic.

The section on Fusain (pp. 261–262) seems to contribute very little in support of the thesis. The mode of origin of fusain is acknowledged to be unsettled, which presumably means that its chemical nature is also unsettled. Even though there may be no fundamental difference between fusain and vitrain, there appears to be a fundamental difference between fusainization and vitrainization. By the coalification process vitrain approaches or possibly even attains to the composition of fusain, but in the low and intermediate ranks of coal these ingredients appear to be very different substances, in spite of the fact there may be gradations from one type of material to the other.

The "Phyterals" (p. 262) provide as much or more difficulty than fusain. Dr. Lahiri regards the transformation into coal of the "bituminous" phyterals —spore coats, cuticles, etc.—as fossilization comparable to the silicification of wood. He believes that these substances in coal are fossils and not "relics," acknowledging, however, the common idea that the phyterals represent original plant material. The fossilization, according to Dr. Lahiri, apparently takes place by the diffusion of "vitrain-like bitumen" into the spore coats and cuticles. Just as is the case with the formation of vitrain from wood, a difficulty with this idea is that more or less isolated spores, into which there is no possibility of diffusion of "vitrain-like bitumen," partake of the same coalification changes as do spores making up part of the coal bed.

No colloidal implications are indicated in the section on "Clarain and Durain" (p. 263). However, the statement that "A realistic approach to a definition of these constituents macroscopically in terms of thickness of vitrain is welcome" needs clarification. The thickness of vitrain bands is not used as a basis for differentiating clarain and durain but as a basis for separating vitrain from clarain. The differentiation of durain is accomplished by demonstrating the presence of a considerable amount of opaque matter. The question of how thin a band of vitrain may be and still be recognized as an individual macroscopic ingredient and not a component of a band of clarain must be settled arbitrarily and, if possible, on the basis of some distinction that has practical significance.

The idea that graphite is not the metamorphic end product of coal seems to be favored by some chemists. It is quite possibly correct that the end product of the organic material is anthracite, graphite obviously not being coal. This is a problem that is appropriate and timely for geochemical investigation and elucidation, in geologic as well as chemical phraseology.

One additional comment is offered, bearing on a more or less incidental statement made by Dr. Lahiri (p. 258, first paragraph): "For example, it is possible that conditions at this stage indicate whether bituminization or oil formation will take place." One is impelled to ask whether or not this statement implies that some of the accumulations of plant debris (peats) have actually been altered to petroleum during the diagenetic stage. This would seem to suggest that the absence of coal above certain root-bearing seat rocks such as underclays is due to the fact that the coal has been altered to petroleum during the diagenetic period. This idea needs considerable elaboration to be accepted.

G. H. CADY.

URBANA, ILLINOIS,
May 26, 1952.

REVIEWS

Principles of Geochemistry. By BRIAN MASON. Pp. 276; figs. 42. John Wiley & Sons, Inc., New York, 1952. Price, $5.00.

The appearance of "Principles of Geochemistry" is gratifying. The new field of geochemistry has been rapidly developing to play an important role in geology. There has been need for a brief one-semester textbook on the subject. With its carefully selected references it will prove valuable to both teachers and research workers. The chapters of the book concern The Earth in Relation to the Universe, The Structure and Composition of the Earth, Some Thermodynamics and Crystal Chemistry, Magmatism and Igneous Rocks, Sedimentation and Sedimentary Rocks, The Hydrosphere, The Atmosphere, The Biosphere, Metamorphism and Metamorphic Rocks, and The Geochemical Cycle.

The point of view of the whole book, as it appears to the reviewer, is to set forth principles and facts that every geologist should know. The author has succeeded by not requiring too great prior knowledge, by his choice of material, and by his logical presentation in a very interesting manner.

The thermodynamic chapter is probably the sketchiest of the several separate subjects treated but this is doubtless due to the fact that the subject matter of thermodynamics does not yet embody geologic facts to the extent that it should. More geologic thinking in terms of the principles of thermodynamics is in the offing.

Another creditable feature of the book is that it stresses the urgent need for more persistent efforts to interpret geology in terms of the principles of physics and chemistry.

M. M. LEIGHTON.

ILLINOIS GEOLOGICAL SURVEY,
URBANA, ILL.,
June 10, 1952.

Monographien der Deutschen Blei-Zink-Erzlagerstaetten, Monographie 1, Die Blei-Zink-Erzvorkommen des Ruhrgebietes und seiner Umrandung. By JULIUS HESEMANN AND ANDREAS PILGER. Pp. 184; figs. 96; pls. 18. Geol. Jahrbuck Beiheft 3. Lagerstaettenausschuss der Gesellschaft Deutscher Metallhuetten- und Bergleute e.V., Clausthal-Zellerfeld, Germany, 1951. Also obtainable through the Amt fuer Bodenforschung, Hannover.

The German association of metal mining engineers (Gesellschaft Deutscher Metallhuetten- und Bergleute e.V.) decided in 1948 to revive the committee on ore deposits (Lagerstaettenausschuss). This organization proposed to undertake a detailed scientific investigation of German ore deposits and to place their findings at the disposal of the public. The first task was to prepare a series of monographs on lead-zinc deposits with the collaboration of individual specialists, state geologic organizations, mining companies and universities for the purpose of solving exploration and practical mining problems as well as problems of an academic nature. The lead-zinc deposits of the Ruhr basin and its surroundings (in two volumes) is the first monograph. The first volume, a typical German handbuch, deals exclu-

sively with the Auguste Victoria mine in Marl-Huels, Westphalia. The second volume will be published shortly.

The Auguste Victoria mine started producing in 1938 and by 1948 two million tons of ore had been extracted averaging 7% zinc and 4% lead. The ore occurs in the Blumenthaler fault in folded Carboniferous strata. The authors present a detailed discussion of the general geology of the area, of the stratigraphy, structure, mineralogy and paragenesis, as well as of mining and milling methods. No geophysical investigations were carried out and the geochemical research is limited; this is particularly surprising as the chairman of the committee on ore deposits in his introduction stressed the importance of these new tools in ore study.

As five years of intensive studies of lead-zinc deposits have been allowed for the completion of this project and 2,000 to 2,400 pages have been set aside for publication of the results, the economic geologist will be able to look forward to some interesting new revelations in the field of lead and zinc.

GERALD M. FRIEDMAN.

UNIVERSITY OF CINCINNATI,
CINCINNATI 21, OHIO,
June 12, 1952.

The Geology and Mineral Resources of the Neighbourhood of Kuantan, Pahang. By F. H. FITCH. Pp. 144; figs. 30; pls. 14; 5 maps in pocket. Geological Survey Department, Federation of Malaya ,Kuala Lumpur, Malaya, 1952. Price, $6.00 (Straits).

This careful piece of geologic work summarizes the areal geology, structure, and mineral deposits of the region near Kuantan. After treating of geomorphology sediments, igneous rocks, and structure, there is a chapter on heavy minerals and another on changes of sea level. Under Economic Geology are included discussions of metallic and nonmetallic ores and minerals, chiefly tin and tungsten. The major part of the Memoir is given to description of the mines of the Pahang Consolidated Co., Ltd., which is the largest operating underground tin mine in the world. Since 1888 it has produced 88,000 tons of tin concentrates and has 180 miles of underground workings. The cassiterite occurs with sulfides and arsenides of iron, copper, cobalt, lead, and zinc. Little tourmaline or greisen accompanies the ore. The ore occurs in lodes formed by hydrothermal replacement of shale.

The Future of Our Natural Resources. Special volume of The Annals of the American Academy of Political and Social Science, edited by STEPHEN RAUSHENBUSH. Pp. 275. Philadelphia, Pa., May, 1952. Price, $2.00.

This special volume is a collection of writings by 24 authors, each of whom stands high in his particular field. The volume is divided into six parts, namely, The Setting of Conservation, Mineral and Energy Resources, Forests, Soils, Water, and General.

The Setting of Conservation is undertaken by Stephen Raushenbush, R. O. Beatty, and John H. Baker. In this, the broader fields of conservation, its movement, and the citizen's part are considered.

Mineral and Energy Resources includes the following articles: Our Future Dependence on Foreign Minerals by Alan M. Bateman; What is Involved in Metals Conservation Today? by Howard A. Meyerhoff; The Fuel Complex: A Projection by George A. Lamb; Adequacy of Our Mineral Fuels by Robert E. Hardwicke; International Fuel Economy by Eugene Ayres; and Conservation of Hydroelectric Power by Paul J. Raver.

Forests includes 5 articles, and Soils 4 articles dealing with maintenance, productivity, restoration, reclamation, analysis of land use, and a rounded conservation problem. Water Resources includes the following articles: The Work of the President's Water Resources Policy Commission by Robert G. Snider; Water: West by Morris E. Garnsey; Water Supply—The Industrial East by Stephen Bergen; and Soil Conservation and Floods. The General section contains two articles: Labor Looks at Conservation and Development by Anthony Wayne Smith; and Conservation and Wise Utilization of Natural Resources in Canada by Major-General Hugh Andrew Young.

The volume is another one of those well rounded special numbers gotten out by the academy in recent years and gives an enlightening outlook on future national resources. It is a volume that should be widely read by geologists, geographers, economists, and particularly by members of the several government agencies who deal with natural resources and the policies associated therewith.

Gesteine und Minerallagerstätten, Band II, Exogene Gesteine und Minerallagerstätten. By PAUL NIGGLI. Pp. 554; figs. 181. Verlag Birkhauser Basel, Switzerland, 1952. Price, Fr. 49.40.

This Volume II, written in German from the pen of one of the world's outstanding scholars in this field, is a welcome addition to the author's Volume I, Allgemeine Lehre von den Gesteinen und Minerallagstätten, which appeared in 1948. This volume treats of the rocks, soils, and of certain mineral deposits that originate through weathering processes and sedimentation. A third volume is yet to appear. The present volume is a mineralogical, petrographical, and geochemical treatment of the subject.

The two sections under Part I deal first with weathering processes, migration of colloids and solutes, classification of weathering products, and molecular and iron dispersion. The second section treats of the soil and soil profile. Part II, Die Böden, is divided into 6 sections, each of which deals with the origin, petrologic features, and geochemistry of different products of weathering. These are clastic rocks, argillaceous, saprolite, and humus sediments, carbonates, phosphates, evaporites, snow and ice, and sedimentary petrographic provinces. Extensive references follow each section.

The mineral deposits that are discussed are chiefly bauxite, clays, fuller's earth, meerschaum, iron and manganese oxides, phosphates, and evaporites.

The full treatment accorded to the various weathering and depositional products will make this book a necessary reference for all geologists.

BOOKS RECEIVED.

H. R. TREMAINE.

U. S. Atomic Energy Commission—Oak Ridge, Tennessee, 1951–52.

RMO-801. Geology and Mineralization of Hunt's Mesa, Monument Valley, Arizona. JOHN W. CHESTER. Pp. 9; figs. 2. *Location, accessibility, structure, uranium occurrences, and sampling.*

RMO-802. Geology and Ore Deposits of Mesa VI Lukachukai District, Arizona. P. C. ELLSWORTH AND K. G. HATFIELD. Pp. 11; pl. 1. *Location, accessibility, previous examinations, regional geology, and uranium deposits of Mesa VI.*

RMO-803. Geology and Ore Deposits of Mesa VII Lukachukai District, Arizona. J. W. KING AND P. C. ELLSWORTH. Pp. 7; pl. 1. *Location, accessibility, stratigraphy, structure, and uranium deposits of Mesa VII.*

RMO-837. Annual Report for July 1, 1950 to June 30, 1951, Part II. JOHN W. GRUNER. Pp. 25. *Origin of uranium deposits in Shinarump Formation, general data, features common to Shinarump sediments in which deposits are found, features found in most uranium deposits in Shinarump, and possible hypotheses of the origin of the uranium deposits.*

RMO-896. Geology and Uranium Deposits of Marysvale, Utah. ALLEN O. TAYLOR, T. P. ANDERSON, W. L. O'TOOLE, G. G. WADDELL, A. W. GRAY, H. DOUGLAS, C. L. CHERRY, AND R. M. CAYWOOD. Pp. 31; pl. 1. *Previous examinations, recent geologic studies and mapping, regional geology, uranium mineral deposits, hydrothermal alteration, and bibliography.*

TEM-133-A. The Mike Doyle Carnotite Deposit, El Paso County, Colorado. E. P. BERONI AND R. U. KING. Pp. 6; figs. 2. *Preliminary report on the geology and radioactive deposits of the area.*

Office of Naval Research, Department of the Navy—Baltimore, Maryland, 1952.

Progress Rept. 1, 2. Soils, Terraces and Time in the Chesapeake Bay Region. V. P. SOKOLOFF. Pp. 13. *In 2 parts—rates of soil formation studies including laboratory possibilities and lead; salts and some trace metals, at Ocean City, Md.*

Progress Rept. 3. Soils, Terraces and Time in the Chesapeake Bay Region. V. P. SOKOLOFF. Pp. 12; tbls. 3. *Notes on pedogenesis—materials, procedures, results, and discussion.*

Mining Development in Asia and the Far East during 1951. ECONOMIC COMMISSION FOR ASIA AND THE FAR EAST. Pp. 50. United Nations Economic and Social Council, Lake Success, N. Y., 1952. *In 2 parts—general features and country summaries.*

The Earth Science Digest. B. J. BABBITT, EDITOR. Pp. 49; figs. 20. Bi-monthly publication, Chicago, Ill., July, 1952. Price, 35 cts. *Articles pertaining to earth science interest.*

The Oil Producing Industry in Your State. Pp. 126; tbls. 3. The Independent Petroleum Association of America, 1952 edition, Tulsa, Okla. *Statistical record of oil and gas production in America with a page devoted to each state.*

Departments of Geological Science in Educational Institutions of the United States and Canada. SHEPARD W. LOWMAN, EDITOR. Pp. 173. American Geological Institute, Rept. 6, Washington, D. C., March, 1952. Price, $1.00. *A directory referring to the geologic departments in the various universities of the U. S. and Canada.*

Antimony, 3rd Edit. C. Y. WANG. Pp. 170; figs. 27; tbls. 19. Charles Griffin & Co., Ltd., London, 1952. *Brief chapters on geology, metallurgy, uses, and economics of antimony. Geology includes ore minerals, occurrences, genesis, classification, metallogenic provinces, descriptions by countries, and bibliography.*

California Journal of Mines and Geology. Pp. 190; figs. 268; map in pocket. California Div. Mines, Vol. 48, No. 2, San Francisco, 1952. *Mines and mineral resources of Yuba County, by J. C. O'Brien; and a supplement—Fabricas: a collection of contemporary pictures and statements on the mineral materials used in building in California prior to 1850, by Elizabeth L. Egenhoff.*

Georgia Geological Survey—Atlanta, 1949–1952.

Bull. 55. Geology and Ground-Water Resources of the Atlanta Area, Georgia. S. M. HERRICK AND H. E. LEGRAND. Pp. 124; figs. 9; pls. 2. *Climate, physiography, geology, ground water, rock formations and their water-bearing properties, and county descriptions.*

Bull. 56. Short Contributions to the Geology, Geography and Archaeology of Georgia. Pp. 160; figs. 26. *24 contributions by different authors.*

Bull. 57. Geology and Mineral Resources of the Dalton Quadrangle, Georgia-Tennessee. ARTHUR C. MUNYAN. Pp. 128; figs. 6; pls. 9; 2 maps in pocket. *Physiography, stratigraphy, structure, mineral resources, geologic history, and references.*

Bull. 58. Geology of the Crystalline Rocks of Georgia. GEOFFREY W. CRICKMAY. Pp. 54; figs. 9. *Stratigraphy, igneous rocks, mixed rocks, structural geology, and conclusions.*

Illinois Geological Survey—Urbana, 1952.

Circ. 177. Market Outlook for Sulfur Recoverable from Coal. WALTER H. VOSKUIL. Pp. 23; tbls. 7. *The sulfur market problem and sources of sulfur.*

Circ. 178. Some Observations on the Blending of Coals for Metallurgical Coke. FRANK H. REED, H. W. JACKMAN, O. W. REES, AND P. W. HENLINE. Pp. 8; tbls. 6. *Use of Gieseler plastometer, cost analysis, discussion, and conclusions.*

Circ. 179. Short Papers on Geologic Subjects. Pp. 66; figs. 26; tbls. 7. *Major Aquifers in Glacial Drift near Mattoon, Illinois, by John W. Foster; Notes on the Illinois "Lafayette" Gravel, by J. E. Lamar and R. R. Reynolds; Cambrian and Lower Ordovician Exposures in Northern Illinois, by Raymond S. Shrode; Revision of Croixan Dikelocephalidae, by Gilbert O. Raasch.*

Circ. 180. Some Important Aspects of Water Flooding in Illinois. PAUL A. WITHERSPOON. Pp. 14; tbl. 1; figs. 11. *Primary oil production, vacuum, and repressuring operations, water flooding operations, locating injection waters, flooding multiple producing zones, clay mineralogy and water flooding, and estimated secondary oil reserves.*

Indiana Department of Conservation—Bloomington, 1952.

Circ. 1. Geologic Formations on which and with which Indiana's Roads are Built. CHARLES F. DEISS. Pp. 17; figs. 3; pls. 9. *Geologic history of Indiana, distribution of potential quarry sites, types of highway subgrades, and conclusions.*

Map 1A. Oil and Gas Field Map of Indiana. COMPILED BY T. A. DAWSON AND M. A. LOWRANCE. *Scale, 1/500,000.*

Kansas University and Geological Survey—Lawrence, 1952.

Bull. 94. Ground-Water Resources of Pawnee Valley, Kansas. V. C. FISHEL. Pp. 144; figs. 12; pls. 6 (3 maps in pocket). *Geography, geology in relation to ground water, stratigraphy, source, occurrence, and movement of ground water, hydrologic properties of the water-bearing materials, ground-water levels and their significance, irrigation in Pawnee Valley, availability and chemical character of ground water, quality in relation to water-bearing formations, records of wells, and logs of test holes and wells.*

Bull. 96, Pt. 5. Geology and Ground-Water Resources of the Kansas River Valley between Lawrence and Topeka, Kansas. STANLEY N. DAVIS AND WILLIAM W. CARLSON. Pp. 73; figs. 8; tbls. 7; pls. 7. *Geography, geomorphic development, ground water, potential development, quality, records of typical wells, and logs of test holes and measured stratigraphic sections.*

Bull. 96, Pt. 6. Experimental Production of Feldspar and Silica from Several River Sands in Kansas. FRANK W. BOWDISH AND RUSSELL T. RUNNELS. Pp. 21; figs. 3; tbls. 11. *Samples, preliminary tests, large-scale tests, chemical analysis of products of large-scale tests, and summary.*

Map. Graphic Column of Kansas Rocks. RAYMOND C. MOORE, JOHN C. FRYE, J. M. JEWETT, WALLACE LEE, AND HOWARD O'CONNOR. *Approximate vertical scale: 1 in. = 85 ft.*

Ohio Department of Natural Resources—Columbus, 1951–52.

Bull. 22. The Water Resources of Clark County, Ohio. STANLEY E. NORRIS, WILLIAM P. CROSS, RICHARD P. GOLDTHWAIT, AND EARL E. SANDERSON. Pp. 82; tbls. 18; pls. 29 (2 maps in pocket). *Climate, surface and ground water resources, quality of the water, and well records.*

Rept. Inv. 10. Oil and Gas in Perry County. ROBERT L. ALKIRE. Pp. 64; figs. 8; tbls. 6; pls. 4 (3 in pocket). *Producing sands, well cutting sample study, method of drilling, development by townships, and secondary oil recovery.*

Rept. Inv. 13, Pt. 1, 2. Oil and Gas Well Drilling Statistics for 1951. COMPILED BY ROBERT L. ALKIRE. **Oriskany Sand Study.** JOHN F. HALL. **Clinton Gas Pool.** HENRY BELDEN. Pp. 137; figs. 16; tbls. 2; pl. 1. *Wells drilled in Ohio 1888–1951, oil and gas production charts, well sample cuttings index, and excerpts from previous reports.*

Ann. Rept. Division of Water. C. V. YOUNGQUIST. Pp. 39; figs. 17.

Geology of the Oiseau (Bird) River Area, Lac du Bonnet Mining Division. J. F. DAVIES. Pp. 24; 1 map. Manitoba Dept. Min. Nat. Resources, Pub. 51–3, Winnipeg, 1952. *General geology, structural geology, and economic geology of the area.*

Ontario Department of Mines—Toronto, 1952.

60th Annual Report, Vol. LX, Pt. III, 1951. Pp. 95; tbls. 13. *Natural Gas in 1950; and Petroleum in 1950, by R. B. Harkness; and Logs of Wells in 1950.*

Prel. Rept. 1952–4. Copper, Nickel, Lead, and Zinc Deposits of Ontario. JAS. E. THOMSON AND RESIDENT GEOLOGISTS. Pp. 21; tbls. 15; maps 2. *Production, geology of copper and nickel deposits, geology of lead-zinc deposits, and explanation of tables.*

Ind. Min. Circ. 3. Feldspar in Ontario. D. F. HEWITT. Pp. 13; figs. 2; 1 map; 1 graph. *Composition and properties, grades, specifications, and uses; origin and mode of occurrence, grade and evaluation of feldspar deposits, mining, and marketing feldspar.*

Vermiculite. E. R. VARLEY. Pp. 69; fig. 1. Colonial Geol. Surveys, Min. Resources Div., H.M.S., London, 1952. Price, 7s. 6d. *Study of vermiculite, uses, occurrence in United Kingdom, Colonial territories, Commonwealth countries, and foreign countries.*

The Albite-Riebeckite-Granites of Nigeria. R. A. MACKAY, K. E. BEER, AND J. E. ROCKINGHAM. Pp. 25; maps 5; graphs 3 (in pocket). Dept. Sci. Ind. Research, Geol. Survey and Mus., H.M.S., London, 1952. Price, 3s. 6d. *Geology of unusual granites carrying uranium and niobium; procedure, detailed geology, radiometry, and conclusions.*

The Australian Mineral Industry, Vol. 4, No. 3. Pp. 30; tbls. 7. Australian Bur. Min. Resources, Geol. Geophysics, Victoria, 1952. *8 chapters including mineral and metal controls, current market prices, smelter and refinery production, and imports and exports of minerals and metals in Australia for third quarter of 1951.*

Pt. 1, Geology of Portion of the Mt. Margaret Goldfiield. R. A. HOBSON AND K. R. MILES. **Pt. 2, Garnetised Gabbros from the Eulaminna District, Mt. Margaret Goldfield.** K. R. MILES. Pp. 136; figs. 15; tbls. 14; pls. 3 (in pocket). *Physiography, general geology, petrography, structural geology, ore deposits, prospecting recommendations in western Australia; field occurrence and garnetised gabbros from other countries.*

Indian Minerals. Pp. 162; 1 map. India Geol. Survey, Vol. 4, No. 3, Calcutta, 1950. Price, Rs. 2/- or 3 s. *Extraction of copper at the Moubhander works; mineral production of the Indian union; bauxite of Khariar Highlands, Orissa; Indian Tertiary coal; mineral digest; and trade and commercial intelligence.*

Ministerio de Minas e Hidrocarburos—Caracas, Venezuela, 1951–52.

Rev. 5. A. VIVAS RAMÍREZ, A. D. AGUERREVERE, AND STAFF. Pp. 139; maps 2; 1 graph. *Economic geology of the coal mines of the "Cazadero No. 1," in Lobatera del Estado Táchira; elements of the Derecho Minero; conservation of petroleum and gas in Venezuela; and other studies of hydrocarbons.*

Bol. 71. Actividades Petroleras. Pp. 17.

Bol. 73. Actividades Petroleras. Pp. 13.

Bol. 74, 75. Actividades Petroleras. Pp. 17.

Dell'Istituto di Geodesia, Topografia e Fotogrammetria—Milano, 1950–51.

Pub. 70. Collegamento gravimetrico delle stazioni di Padova, Bologna e Milano per mezzo di un gravimetro Western G. 4 A. M. CUNIETTI. Pp. 10; tbls. 4. *Discussion of measurements made with Western G. 4 A n. 48 gravitymeter to connect gravity stations of Padova, Bologna and Milano of the Italian fundamental network. Comparisons are given with the previous pendulum gravity data and at last some considerations about gravitymeter's constant precision.*

Pub. 72. Sulla smagnetizzazione di gravimetri astatici. M. CUNIETTI. Pp. 7; figs. 2. *With some theoretic arguments it is shown, well proved by the sperimental results, that in the process of de-magnetisation of the astatic gravimeters, the influence of terrestrial magnetism is not negligible.*

Pub. 73. Spigolando tra i Compiti della S. I. F. E. T. G. CASSINIS. Pp. 3.

Pub. 74. Rilievo Gravimetrico del Comune di Milano. L. SOLAINI AND M. CUNIETTI. Pp. 15; figs. 6; 1 map. *A detailed gravimetric survey covering the area of the city of Milan is described. After a discussion of the results and an accurate elimination of the regional gradient, the remaining local anomalies are examined.*

Tohoku University—Sendai, 1952.

Sci. Rept. Vol. 4, No. 2. Pp. 76; figs. 26; tbls. 23; pls. 9. *Occurrence of tellurium and barium Minerals in Japan, by Manjiro Watanbe; Magnetic Orientation of some Rocks in Relation to their Geologic Occurrence (I) Magnetic Contact Effect of Intrusion, by Iwao Kato; A New Find of Gypsum from the Matsuo Sulphur Mine, Iwate Prefecture, by Keiichi Omori and Jun-ichi Kitahara; Hausmannite and Tephroite from Himegamori, Iwate Prefecture, by Keiichi Omori, Shuzo Hasegawa, and June Otomo; Thermal Study on the Intergrowth of Chalcopyrite and Sphalerite, by Asahico Sugaki and Noritoshi Yamae; and Molybdenite Deposits in Northern Japan, by Manjiro Watanabe and Asahiko Sugaki.*

No. 41. Geology of the Takanosu, Odate and Yonaizawa Districts, Kita-Akita-gun, Akita Prefecture. RIKIZO IMAIZUMI AND TAMIO KOTAKA. Pp. 26; figs. 5; tbl. 1; 1 map (in pocket). *Geomorphology, stratigraphy, geologic structure, correlation, and geologic history of the area.*

Météorologie Nationale, Ministère des Travaux Publics des Transports et du Tourisme—Paris, 1949–1950.

Mem. 34. La pratique de la pluie artificielle. R. EYRAUD. Pp. 44; figs. 9. *Formations of clouds, precipitation, temperatures, etc.*

Fasc. II. Bibliographie Météorologique Internationale. Pp. 261. *Meteorology, structure, mechanics, and temperature of the atmosphere in general, climate, etc.*

Fasc. III. Bibliographie Météorologique Internationale. Pp. 193. *Astronomy, geography, oceanography, meteorology, etc.*

Fasc. IV. Bibliographie Météorologique Internationale. Pp. 188. *Planets, movements in the air, transformation of solids and liquids, geology, stratigraphy, etc.*

Polskie Towarzystwo Geologiczne—Kraków, 1951.

Tom. I. Regionalna Geologia Polski, Karpaty, Stratygrafia. Pp. 185.

Pars. I. Mieczaki Mioceńskie, Ziem Polskich I Krajów Przyleglych. Pp. 200, figs. and tbls.

SCIENTIFIC NOTES AND NEWS

THOMAS P. THAYER, U. S. Geological Survey, in recognition of his work on the geology of the Bomi Hills iron deposits, Liberia, was made a Commander of the Star of Africa. The order was conferred by President Tubman, in Monrovia. Thayer returned to the United States in mid-June.

W. D. JOHNSTON, JR., Chief, Foreign Geology Branch, U. S. Geological Survey was made an officer in the Order of the Southern Cross (Cruzeiro do Sul), in recognition of his geologic work in Brazil.

NORMAN D. NEWELL, Professor of Geology at Columbia University, and Curator of Fossil Invertebrate at the American Museum of Natural History, will head a team of 8 scientists to conduct an ecological survey on Raroia Atoll where the Kontiki expedition ended in 1947. Prof. Newell will concern himself mainly with the origin of Atoll. Other members of the expedition are DR. DANIELLSON, of Sweden, who was on Kontiki and who will do anthropological work; JOHN BURN, assistant to Prof. Newell; DR. MAXWELL DOTI, of the University of Hawaii and his assistant, W. JAN NEWHOUSE, of the University of New Hampshire, to study marine and terrestial plants; DR. JOSEPH E. MORRISON of the U. S. National Museum who will specialize in marine invertebrates; and ROBERT R. HARRY, Zoologist. The expedition was planned by the Pacific Science Board of the National Research Board and financed by a grant of the U. S. Office of Naval Research. Most of the investigating done will be diving operations in the lagoon.

The "SOCIEDAD VENEZOLANA GEOFISICA" (Venezuelan Geophysical Society) was formed by 43 exploration geophysicists who met in Caracas, Venezuela, on May 26. The group voted to form the society along the same lines and for the same purpose as the SEG. Regular meetings will be held for the discussion of current exploration problems encountered in Venezuela, and consideration will be given to affiliation at a later date as a local section of the SEG. W. C. MERRITT, of Creole Petroleum Co., was named chairman of the constitution committee.

E. O. CHISHOLM, resident geologist for the Ontario Department of Mines at Kenora for the past 7 years, has left the department staff to take up private practice.

The FULBRIGHT awards for lecturing and advanced research include Denmark, Egypt, France, Greece, Iraq, Austria, Belgium and Luxenbourg, Italy, Netherlands, Norway, Turkey, The United Kingdom and Colonial Dependencies. Also included are awards for Japan, Pakistan, and the Union of South Africa. A Fulbright Agreement has recently been signed with the Union of South Africa and a very small program will be initiated for 1953–54. Applications close on October 15, 1952.

ROBERT F. JOHNSON, geologist with the U. S. Geological Survey, transferred from the Mineral Deposits Branch to the Foreign Geology Branch in April for an assignment with the Survey field party in Lima, Peru. He attended a Point IV orientation course at the State Department in Washington, D. C., before leaving for Peru on May 6.

Appointment was made of RICHARD BREWER, of The Atlantic Refining Co., Shreveport, as general chairman of the 6th annual midwestern meeting of the Society of Exploration Geophysicists. The meeting will be held November 13 and 14, 1952, in Fort Worth, Texas, and sponsored by the Fort Worth, Dallas, Midland, Tulsa, and Shreveport local sections of the SEG with the Shreveport group in charge of arrangements.

The BILLINGS GEOLOGICAL SOCIETY of Billings, Montana, will hold its annual field conference September 4–7, 1952, in the Black Hills and Williston Basin Area, with headquarters at Deadwood, South Dakota. Field trips in the north part of the Black Hills will be held Friday and Saturday, September 5 and 6; and an optional trip will be held north of the Black Hills in the central part of the Williston Basin on Sunday, September 7. GEORGE DARROW, of Billings, Montana, is general chairman, and FRANK P. SONNENBERG is editor of the guidebook. Those wishing to attend should write to John M. Parker, Box 797, Billings, Montana, registration and housing chairman.

The NEW MEXICO GEOLOGICAL SOCIETY will hold its 3rd annual field conference October 3–5, 1952, in the Rio Grande Trough of central New Mexico. Participants will register in Santa Fe on October 2, and will proceed south along the east side of the Sangre de Cristo and Sandia Ranges (with a side trip to Sandia Crest at 10,678 feet elevation); the east side of the Manzanita and Manzana Mountains; Abo Canyon and the north end of Chupadera Mesa; the Socorro Mountains; and the north end of the Caballo Mountains and the Jornada del Muerto, site of recent wildcat drilling. Sections of rocks ranging from Precambrian to Recent are well-exposed in the areas, and correlation of the Paleozoic and Mesozoic sections will be emphasized. Side trips will be made to one of the largest perlite deposits in the United States, operated by the Great Lakes Carbon Corporation; and to the Carthage coal field, both near Socorro. The conference will end Sunday afternoon near Truth or Consequences.

The UNIVERSITY OF NEVADA has been awarded a $60,000 contract by the U. S. Atomic Energy Commission for developmental studies of methods of processing uranium ores and concentrates. The university will study beneficiation of low-grade uranium ores and extractive metallurgy for the recovery of uranium and other values from ores and concentrates.

LEON W. DUPUY, of Silver Spring, Md., has been appointed as coordinator of mineral resources studies of river basins for the Bureau of Mines. Wise development and utilization of all resources in the several river basins of the United States is the ultimate objective of river basin studies now under way. Planning is done in co-operation with the States on an interdepartmental basis, where individual programs for the conservation and development of all natural resources are fitted into Interior's inclusive, long-range program. The Bureau of Mines is presently carrying on mineral resources investigations in 7 project areas, according to John J. Forbes, Bureau Director. These are the Pacific Northwest, Colorado-River-Great Basin, Missouri River Basin, Arkansas-White-Red River Basin, the New York and New England area, and the Alaska area.

ESPER S. LARSEN, JR., of the U. S. Geological Survey, has been elected by the Geological Society of London as one of its foreign members.

The U. S. Geological Survey has reopened its uranium testing laboratory at the University of Alaska in the Fairbanks area in an effort to aid uranium prospectors in their search for this critical mineral. The address is ALASKAN TRACE ELEMENTS UNIT, Geological Survey, P. O. Box 1088, Fairbanks, Alaska.

COLUMBIA UNIVERSITY announces the departure of a group of some of the nation's foremost geologists and oceanographers on a major expedition to explore the floor of the Atlantic Ocean. The expedition, sponsored by Columbia University, the Office of Naval Research, the Navy's Bureau of Ships, and the Woods Hole Oceanographic Institution, will begin exploration of the ocean floor off New England. The expedition will return to New York about October 1. Led by W. Maurice Ewing, the 9 scientists in the group will make seismic refraction measurements to determine the thickness of the sedimentation on the ocean bottom and the nature of the rock under it. Another task of the research party will be to take samples of the sediment on the bottom through the use of a special piston "coring" apparatus which was constructed at the Lamont Observatory. At some points in the Atlantic this work will be done in depths as much as 3,100 fathoms (about 19,000 feet). The investigators also hope to secure large samples of water from the ocean bottom on both sides of the mid-Atlantic Ridge. They will extract the carbonate found in this water by shipboard chemical processes and bring the carbonate back to the laboratories at the Lamont Geological Observatory where its "age" will be determined. By the "age" the scientists mean the length of time elapsed since the sample of water lost contact with the atmosphere and sank to the bottom.

The NATIONAL SCIENCE FOUNDATION announces that a Columbia University group will develop plans for a Russian-English scientific dictionary under a National Science Foundation contract with a series of studies which may eventually lead to the compilation of a new, comprehensive Russian-English scientific dictionary.

SAMUEL S. GOLDICH, U. S. Geological Survey, left for Brazil for a reconnaissance examination of the bauxite deposits of the Pocos de Caldas area in Minas Gerais, Brazil, in cooperation with the geologists of the Departamento Nacional da Producao Mineral, who have been engaged in the study of this area for some years. This investigation is a part of a long-term program of cooperative investigation of Brazilian mineral deposits conducted jointly by the Geological Survey and the Brazilian DNPM under the auspices of the office of Technical Cooperation Administration of the Department of State. Similar Point IV investigations have been made of manganese, iron, and other mineral deposits of Brazil.